Wood Chip Heating Of Homes And Other Small Buildings

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WOOD CHIP HEATING

OF HOMES AND OTHER SMALL BUILDINGS:

Heating Equipment Characteristics and Operation

and

Small-Scale Fuel Production

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May 28, 1982

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This report, prepared for Energy, Mines and Resources, Canada and based on information and experience gained through a demonstration funded by the New Brunswick Energy Secretariat, presents an excellent overview of the state of development in the area of wood chip fuels for residential heating.

The technologies under review show potential for the resolution of some safety, environmental, and convenience problems seemingly inherent with conventional wood burning systems. With these automated systems an improvement in combustion efficiency is apparently possible, thereby reducing flammable chimney deposits and lowering harmful emissions. The time required by the homeowner for fire maintenance is less for these systems than for batch feed systems. This factor may serve to increase the market in Canada for wood fuel based heating systems.

For Energy, Mines and Resources, what this report identifies are those elements of the technology that require further study before it can be considered ready for commercialization. The safety aspects and operational characteristics of the combustion equipment must be addressed more fully. To this end, the Combustion Research Laboratories of EMR will be investigating the efficiency and stack emission performance of automated systems. In addition, EMR is supporting the development of standards for automatic wood chip and pellet burning systems by the Canadian Standards Association. Only through testing and certification to recognized standards can the safety of these systems be evaluated and a level of assurance be provided to homeowners who wish to employ these systems to heat their homes.

Further work by the authors of this report, currently funded through the Canada-New Brunswick Conservation and Renewable Energy Demonstration Agreement (CREDA), will address questions in the area of fuel harvesting, handling and storage in the home. The economics of fuel supply, the development of supply infrastructure and solutions to storage related problems in the home remain to be fully examined. The knowledge gained through this study will bring one step closer the ultimate goal of commercialization.

The range of potential advantages of these systems is quite striking. They include a further capacity to displace the use of imported oil, better use of our forest resource, improved safety, cleaner emissions, and opportunities for regional employment. Through the developmental and demonstration stages industry, with the assistance of government, can lay the groundwork so important to the realization of this potential.

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ABSTRACT

Correctly prepared wood chips can be made at relatively low cost from forest wastes and can be burned conveniently, cleanly and efficiently in various types of appliances. Factors to consider when selecting, installing and operating such chip burning equipment are discussed.

Operational methods and silvicultural concerns related to collecting forest material for chip production are dealt with, as are methods for drying and storing the chips.

Key Words: Energy, biomass, wood chip, home heat, farm heat, stoker, preheater, furnace, boiler, harvesting biomass, wood harvesting, woodlot.

WOOD CHIP HEATING OF HOMES AND OTHER SMALL BUILDINGS

PREFACE

This booklet is intended to provide information about characteristics of available central heating systems which burn wood chips and about the production of such chips. The discussion is limited to those heating sytems designed for single family homes, small apartment buildings, small commercial buildings and small institutional buildings. The chip production systems discussed are appropriate for small woodlots and low capital investment. The booklet is directed to those who choose and operate heating plants in such buildings, those who install and service heating equipment and producers of wood chip fuel.

One of the authors, Joakim Hermelin, is a forester with experience in woodlot management and harvesting in Sweden and Atlantic Canada. Tony Short is a mechanical and forest engineer and Marc Schneider is a wood scientist and technologist. The latter two head a wood chip home heating project sponsored by the Energy Secretariat of the Province of New Brunswick. Under this project, they have heated their homes with wood chips for over two years. They also direct a wood fuel chip supply project sponsored by the Governments of Canada and New Brunswick through the Conservation and Renewable Energy Demonstration Program. Much of the material presented in this booklet results, directly or indirectly, from these projects.

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John L. Williamson, Deputy Minister, New Brunswick Energy Secretariat whose enthusiasm, encouragement, help, dedication and vision have made the wood chip burning project and therefore this booklet, possible.

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Lucie Brunelle is the illustrator of this booklet. Tom McKegney helped with the language from a journalist's perspective. Marlene Brown was the unusually competent and enthusiastic typist who also commented from a journalistic viewpoint. Photographic work relative to preparation of the illustrations was done by the New Brunswick Natural Resources Photographic Services Branch.

TABLE OF CONTENTS

		Page
	PREFACE	ii
1.	INTRODUCTION	
1.1	Rationale	1
1.2	Scandinavian Experience with Wood Chip Heating	2
2.	FUNDAMENTALS OF WOOD CHIP HEATING	
2.1	Advantages to Heating Using Wood Chips	5
2.2	Wood Chip Heating Equipment: Alternatives	7
3.	EQUIPMENT INSTALLATIONS	
3.1	Retrofitting in Existing Buildings	10
3.2	New Buildings	14
4.	INSTALLATION AND SAFETY	
4.1	Space Requirements for Equipment and Fuel Storage	16
4.2	Spores and Dust in Fuel Chips	18
4.3	Safety Code Requirements	19
4.4	Insurance Considerations	21
5.	EQUIPMENT	
5.1	Combustion of Wood Chips	23
5.2	Stoker Equipment Description	23
5.3	Stoker Operation and Maintenance	29
5.4	Preheater Equipment Description	31
5.5	Preheater Operation and Maintenance	35
5.6	Performance Analysis	37
5.7	Troubleshooting	39
6.	WOOD CHIP FUEL SUPPLY	
6.1	Harvesting Systems: Pre-Commercial Thinnings	41
6.2	Harvesting Systems: Commercial Thinnings	46
6.3	Harvesting Systems: Clear-Cut or Final Cut	53
6.4	Harvesting Systems: Clean-Up Operations	54
6.5	Farm Tractor Mounted Chipper	54
6.6	Drying	54
6.7	Supply Organizational Possibilities	59

7. EFFECTS OF CHIP QUALITY ON USEFULNESS AND STORABILITY

		Page
7.1	Moisture Content	61
7.2	Density and Species	63
7.3	Wood Chip Fuel Pricing	64
7.4	Chip Size and Distribution	64
7.5	Foreign Matter	68

8. COST ASPECTS

8.1	Equipment Costs	72
8.2	Installation Costs	72
8.3	Service	73
8.4	Fuel Costs	73
8.5	Bin Costs	74

9. SUMMARY 75

APPENDICES

I GLOSSARY OF TECHNICAL TERMS
II CONVERSION FACTORS
III EFFICIENCY CURVES
IV SPECIFICS OF FREDERICTON HOUSES HEATED WITH WOOD CHIPS
V GUIDE FOR FURTHER READING
VI PERSONAL INDEX

LIST OF ILLUSTRATIONS

FIG.		PAGE
1.1	Where to send the wood?	3
2.1	Stoker connected to an appliance	7
2.2	Preheater connected to an appliance	8
3.1	Typical boiler	11
4.1	Chip Stoker Requirements	18
5.1	Transfer box	24
5.2	Overfeed stoker	25
5.3	Underfeed stoker	26
5.4	Underfeed grate	27
5.5	Precombustion stoker	29
5.6	Preheater - general	31
5.7	Preheater - details	33
5.8	Preheater - mechanical controls	34
5.9	Preheater grates - adjustment	35
6.1	Rough limbing	42
6.2	Manual harvesting system	43
6.3	Manual harvesting using a winch	44
6.4	Manual harvesting with winch and forwarder	45
6.5	Whole tree harvesting	47
6.6	Shortwood harvesting with a winch	48
6.7	Shortwood/tree length harvesting	49
6.8	Full tree harvesting	50
6.9	Shortwood harvesting using a forwarder	51
6.10	Tree length harvesting	52
6.11	Drying chips in a bin	57
6.12	Grain dryer used for chips	58
6.13	Ventilation method for drying chips	58
6.14	Harvesting and distribution options	60
III.1	Excess air curves	
III.2	Efficiency curves for bone dry wood	
III.3	Efficiency curve for 25% MC wood	
III.4	Efficiency curve for 40% MC wood	

1. INTRODUCTION

1.1 Rationale

Energy, regardless of its source, is becoming increasingly expensive. Global fossil fuel reserves are finite, and even though one type or another may be considered in plentiful supply at present, there is no guarantee that any given fuel will be readily, or relatively inexpensively, available in a decade or so. It has taken a mere three decades for attitudes about the selection of fuel oil for space heating to change. Conversions to oil from coal, for instance, were being undertaken in the late 1940s and early 1950s. Now, in the early 1980s, economic pressures and governmental policies encourage homeowners and others to convert to energy sources other than oil. One such alternative is wood chip fuel. This alternative is particularly attractive in areas close to forest lands.

There are several wood chip fuelled heating systems that have been developed which will soon be readily available in North America. The Scandinavian countries have been using such systems for some time. This booklet describes wood chip heating systems and how they operate. It also describes the preparation and characteristics of wood chip fuel. The term "moisture content" is used throughout this booklet and is defined in detail elsewhere. Wherever it is used, the values are on a dry wood basis.

The material is presented in two forms. The more general, less technical information is double-spaced. Greater depth discussion is singled space and boxed.

1.2 Scandinavian Experience with Wood Chip Heating

A brief review of what is taking place in the Scandinavian countries can highlight some of the problems we are having or may experience in Canada.

The Scandinavian countries face increasing economic and political pressure to substitute expensive oil energy with alternative sources, one of them being wood fibre. In the process a few key issues have emerged. The goal is to develop energy resources which complement existing industrial uses of wood fibre, not compete with them. The desire is to utilize fibre which today is not consumed by the forest industry such as logging residues, pre-commercial thinning residues, stumps and non-commercial species all of which is also called "forest energy" or "forest biomass".

The Scandinavian forest industry already has a well-developed system to utilize residues such as bark, slabs, sawdust and spent chemicals produced in industrial processes. There are no more energy sources to be found in this sector. They have already been been identified and are well utilized.

To structure the planning of the use of forest energy, four distinct consumer groups have been identified:

1. Individual homes and farms in primarily rural areas.
2. Institutional consumers like schools, hospitals and public buildings.
3. Utilities for production of heat and/or electricity.
4. Forest industries.

It is expected that the production of fuel chips for the first category, individual rural homes and farms, can take place locally, often by the owner or a local contractor. The equipment is relatively cheap and simple. It often uses the farm tractor as a power source. Other existing equipment and resources are often suitable for harvesting, transportation and storage.

The second group, institutional users, require a long term, reliable supply of chips. This group rarely produces its own chips. Instead it will have to purchase from a producer big enough to guarantee delivery. Producers in this category can be a woodlot owner organization, larger contractors or industry with its own harvesting, processing and transportation systems.

The third group, utilities, is similar to group two except that its needs will be much bigger and so will its dependence on secure long-term delivery contracts.

The fourth category, the forest industry, is in the fortunate situation of already having a well developed industrial harvesting, transportation, processing and storage infrastructure. It can very easily expand its normal harvesting systems to include the forest energy component. In many cases the forest industry can also utilize the product (fuel chips) in its existing energy production processes, or it can enter into contracts with consumers of categories two or three (institutions or utilities) for all or part of their requirements.

In the Scandinavian countries, categories one and four are already on an operational scale with development continuing. However, there is substantial hesitation in respect to developing consumers of categories two and especially three. In a tight energy supply situation, it can be tempting to direct industrial raw material to fuel chip production. Utilities or institutions facing a fuel shortage will be able to pay more than the forest industry which has to compete on the world market with its products. The fuel chip producer can get a higher price, but society as a whole may lose, since raw material would be directed to a use which may give a lower overall economic return than if it had been used by industry.

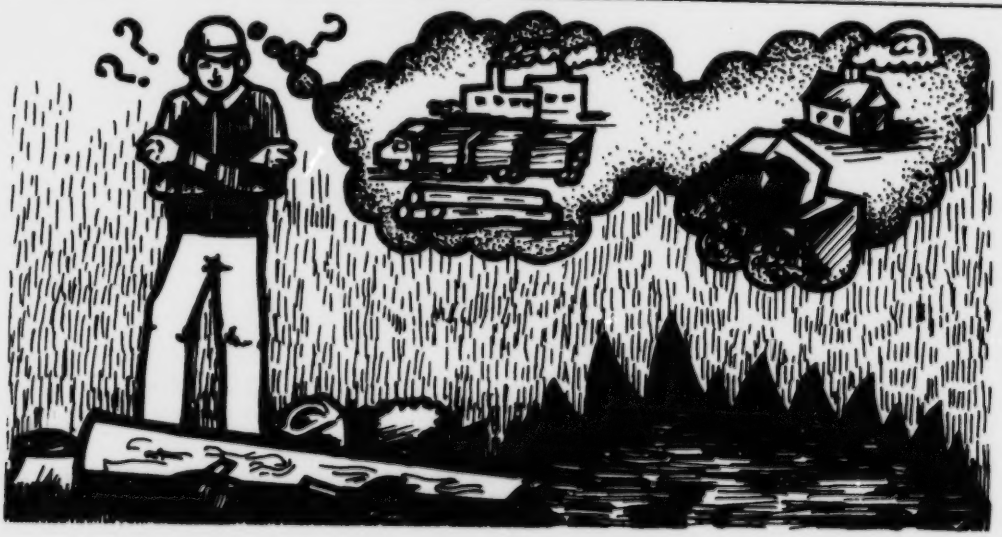


Figure 1.1

The producer's dilemma. Where should the wood go?

The Scandinavian countries have a well-defined and developed silviculture system. There is a substantial skilled labour pool in rural areas. Suitable machinery such as farm tractors, and equipment such as winches, trailers, and chippers exist for harvesting. With this infrastructure, fibre from thinnings and non-commercial species can be routinely harvested and processed into wood chip fuel. Before wood chips are burned extensively for space heat in Canada, equipment for burning them will have to be demonstrated. Also, the infrastructure required to harvest, process and distribute the fuel chips will have to be developed.

2. FUNDAMENTALS OF WOOD CHIP HEATING

2.1 Advantages to Heating Using Wood Chips

2.1.1 Technical and Social Advantages
2.1.2 Convenience
2.1.3 Economic Advantages
2.1.4 Silvicultural Advantages

2.2 Wood Chip Heating Equipment: Alternatives

2.2.1 Stokers
2.2.2 Preheaters
2.2.3 Comparison: Stokers and Preheaters

2. FUNDAMENTALS OF WOOD CHIP HEATING

2.1 Advantages to Heating Using Wood Chips

There are numerous advantages to using wood in chip form rather than in the traditional split stick or chunk form. These fall into four categories.

2.1.1 Technical and Social Advantages

In chip form, fuel wood can be moved from one place to another by various mechanical conveying methods. Wood chips can be dried, delivered and stored very easily.

Wood chip fuel is mechanically added to the fire by a stoker only when heat is required by the house. In a well-designed stoker, the fuel is burned in a small, very hot fire which burns it completely. As a consequence there is little or no visible smoke, creosote deposits are so light as to pose no hazard and little air pollution is produced. Combustion and seasonal efficiencies are high which conserves fuel. Preheater performance is better than most chunkwood appliances but not as good as that of a well designed stoker.

> Chunk fuelwood heaters typically operate at about 50% to 60% combustion efficiency, and perhaps 35% to 40% seasonal efficiency. The chip stokers in the Fredericton test houses have been operating between 70% and 80% combustion efficiency and appear to produce a seasonal efficiency of about 50%.

2.1.2 Convenience

The operator need only ensure that a chip hopper is filled and the heating system will feed itself automatically. Frequency of attention depends upon the size of the chip storage bin and on the amount of

heat required. Stoker equipment now commercially available requires the operator to refill the bin once per day during most of the winter. Only about once per week is required in the "shoulder seasons" (early fall and late spring). Preheater hoppers need more frequent filling. With large stoker bins capable of holding about 2 tonnes of chips, refuelling by the operator would be eliminated since the bin would be filled on a preplanned delivery schedule as can be done with fuel oil deliveries.

2.1.3 Economic Advantages

Wood chip fuel is produced locally and thus returns money to the local community and workforce. The wood chip fuel supply is relatively secure since it is not threatened by distant social or political upheavals.

Fabrication, sales and servicing of equipment to both harvest and burn wood chips can also stimulate local economies.

2.1.4 Silvicultural Advantages

Use of wood chips as fuel creates a market for currently unused woody material. These include limbs and tops of commercial trees, "weed" species of no commercial value, and small trees which are removed during thinning.

Limbs and tops are normally left on the site as they fall, where they gradually decay. In some instances they are removed by manual or mechanical piling and then burning. Sometimes they are bulldozed into windrows to open clear areas for planting. Unless limbs and tops are removed, access to the forest for silvicultural or recreational purposes is impeded. Chipping such material and selling it as fuel allows the woodlot owner to earn additional income while clearing the land of undesirable material. The additional income can be applied to planting the cleared forest.

Thinning improves forest growth. Chipping of material removed by thinning could offset costs of thinning. Similarly, clearing costs could be balanced by revenue from selling chips made from the "weed" species.

2.2 Wood Chip Heating Equipment: Alternatives

There are two basic types of wood chip burning equipment suitable for residential and small commercial/institutional installations - stokers and gravity-fed preheaters.

2.2.1 Stokers

Wood chip stokers consist of a hopper which is used to store a quantity of chips, an electric motor-driven screw conveyor (or auger) to mechanically transport chips from the hopper, and a combustion grate on which the chips burn. In addition, the stoker will have some mechanism to ensure that the chips flow down to the bottom of the hopper, a

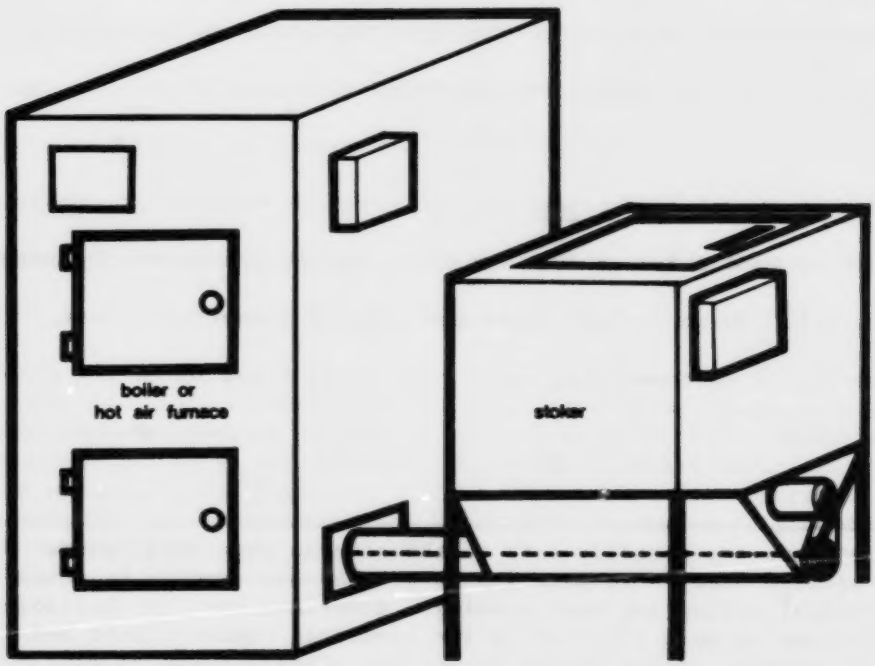


Figure 2.1

General appearance of a stoker connected to an appliance.

back-fire prevention device and the necessary controls to ensure proper operation. Most also have a blower to provide turbulent, high velocity combustion air.

2.2.2 Preheaters

Wood chip burning preheaters have a chip storage hopper which is directly above a firebox grate. Chips are fed by gravity to the firebox. A combustion arch of cast stainless steel or ceramic is located just above the combustion grate in the firebox. Air inlet ducts, a thermostatic draft regulator and an insulated, refractory tunnel leading from the preheater to the furnace or boiler combustion chamber complete the preheater. Such units are similar to sawdust burners used 30 to 40 years ago and currently being revived. Some preheaters have mechanical controls and operate without electricity. Others have electrically controlled dampers.

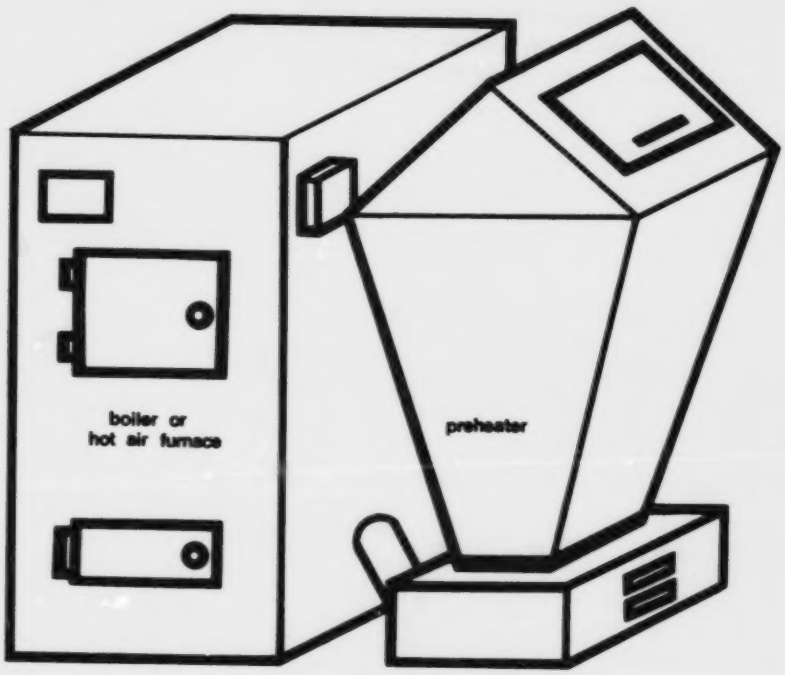


Figure 2.2

General appearance of a preheater connected to an appliance.

2.2.3 Comparison: Stokers and Preheaters

Preheaters have the advantages of:
- somewhat lower initial cost
- no electricity required for operation

but suffer from the following disadvantages:
- require more manual tending
- relatively high fuel consumption
- relatively high minimum heat output may overheat some buildings in fall and spring months
- require wet chips
- leaks in the hopper, or carelessness in closing the hopper may cause a fire hazard.

Stokers have the advantages of:
- ability to burn dry or wet chips
- readily adjustable heat output rates to match requirements
- full thermostatic control as with oil and gas fuelled equipment
- efficient operation
- relatively low fuel consumption
- infrequent attention
- very safe

but suffer from the following disadvantages:
- relatively expensive
- require connection to an electricity supply.

3. EQUIPMENT INSTALLATIONS

3.1 Retrofitting in Existing Buildings

3.1.1 Boilers and Furnaces
3.1.2 Smoke Pipe and Chimney
3.1.3 Plumbing and Ductwork
3.1.4 Controls and Wiring
3.1.5 Back-up Heating

3.2 New Buildings

3.2.1 Fuel Delivery
3.2.2 Fuel Storage
3.2.3 Back-up Heating
3.2.4 Chimney Location

3. EQUIPMENT INSTALLATIONS

3.1 Retrofitting Existing Buildings and Equipment

Existing installations that are most suitable for conversion to wood chip fuel are those now using hot water or forced air for heat distribution. Electric baseboard or ceiling resistance heating systems cannot be directly converted to a central chip-fired system. In such instances, a hot water or forced air system has to be installed in the building to distribute the heat.

3.1.1 Boilers and Furnaces

In most cases, for reasons related to appliance certification and to costs for performing custom modifications, retrofitting a heating system to use wood chips will require installation of a new boiler or furnace. Space permitting, the new appliance can be installed where the original unit had been located. Since current stokers or preheaters must be installed close to the boiler or furnace, consideration has to be given to this when choosing the appliance. Many appliances are designed to accept the stoker or preheater connection on two or more sides.

Wood burning equipment produces fine ash and soot particles which get picked up and carried away from the fire by the combustion gases. These tend to settle on horizontal surfaces in the boiler or furnace and in the smoke pipes connecting the unit to the chimney. For this reason, boilers or furnaces for use with wood chip fuel should be designed so that they are easy to clean. One feature to look for is

vertical rather than horizontal tubes or passageways through their heat exchange section.

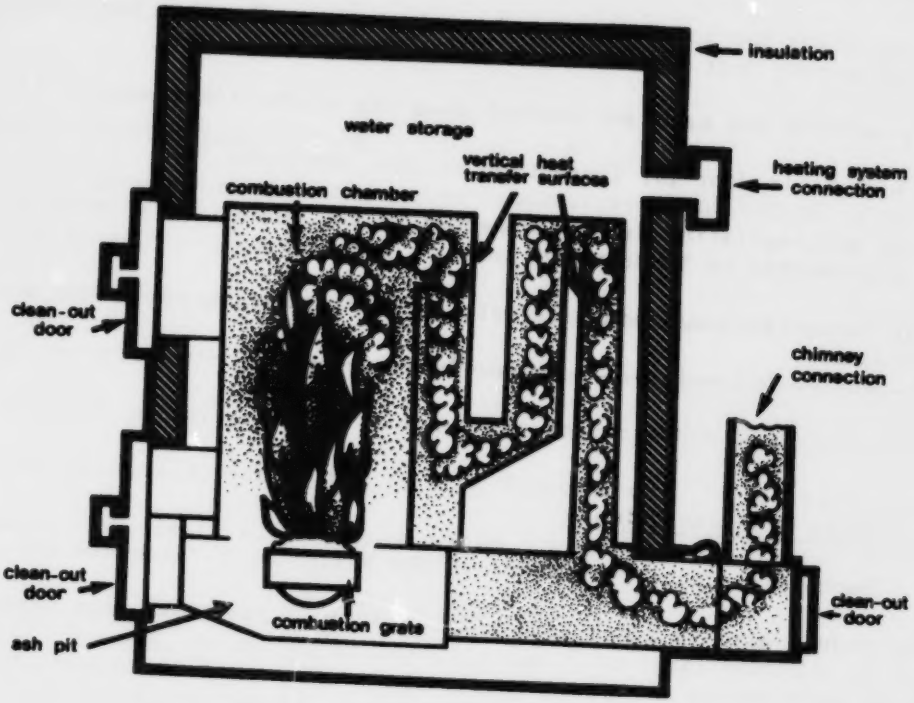


Figure 3.1
Typical Boiler

Factors to look for in a heating appliance include vertical heat transfer surfaces and convenient clean-out openings.

When converting to wood chip fuel it may be possible to retain an existing boiler or furnace. Its suitability depends on the size and design of its combustion chamber and its overall condition. The combustion chamber should allow an opening for connection of the stoker or preheater, and an opening for removal of ash. In such cases a heating contractor could modify the existing boiler or furnace by cutting the necessary openings.

If it is necessary to add an ash pit/combustion chamber extension under the unit, the height of the unit must be increased by about 30 cm (12 inches). Headroom, including all mandatory clearances, must be adequate for this type of modification. In most cases, costs of modifications exceed those of purchase and installation of equipment designed for the job.

Some older boilers and furnaces originally designed for coal burning and more recently converted to oil may be particularly well suited for use as chip wood burners. There should exist:

- provision for inserting the chip apparatus combustion bowl or refractory duct into the combustion chamber,
- provision for easy ash removal from the combustion chamber,
- a suitable door for inspection of fire condition, and
- an air regulating damper connected to the combustion chamber if a preheater is to be used.

If the foregoing conditions are met, then the existing appliance may be retained.

3.1.2 Smoke Pipe and Chimney

Smoke pipe connections between the boiler or furnace and the chimney should also be taken into consideration. The smoke pipe cross sectional area should be approximately the same as that at the outlet from the appliance. The smoke pipe should be as short as possible. A barometric damper should be installed in the smoke pipe, as in an oil burning unit, to permit proper control of the over-fire draft. The chimney, if satisfactory for an oil burning unit, will be adequate for a wood chip fuelled stoker. It is advisable to have the chimney inspected to make sure it is in sound condition. Section 4 discusses Building Code and CSA requirements.

3.1.3 Plumbing and Ductwork

Piping connections between a new boiler and the existing plumbing are simple. This permits great flexibility in location and orientation of the boiler. Ductwork for hot air systems, because of its size,

may pose more difficulties when installing a furnace. Ideally, the furnace should be installed in such a way that the hot and cold air plenums do not require relocation.

3.1.4 Controls and Wiring

Regulation of boiler water temperature or of hot air plenum temperature in stoker systems is identical to that in current oil fired systems. In many cases, the controls fitted to the original oil fuelled heating system can be installed on the wood chip fuelled system. In wiring the stoker to such controls, the stoker motor is connected to the burner terminals, preferably through a contactor. In addition, a second 115 volt supply is wired to the stoker to operate the fire-maintenance timer.

Preheaters do not necessarily use electrical controls or drives but the furnace to which they are connected will need them unless it has a gravity heat distribution system.

3.1.5 Back-up Heating

In cases where a building is likely to be left unattended for any length of time, a supplementary source of heat should be provided. Currently available wood chip fuel systems, while reasonably reliable, are subject to occasional malfunction and interruption of heat supply.

In retrofit situations, one solution is to retain the original heating plant and to have controls installed which would automatically transfer space heating to it. If the chip burner malfunctions and the original boiler or furnace has been removed, an electrical resistance heating unit would probably be the best choice because of size and cost.

In hot water systems, a small electric boiler can be piped into the system along with the wood chip unit. For hot air systems, a duct heater installed between the hot air plenum and the outlet connection to the furnace would suffice. An electric hot air furnace could also be used but would take more room and would probably be more expensive.

Consideration should be given to the size of back-up heating system selected. Its purpose may simply be to maintain some minimum temperature in the building while the building is unoccupied for extended periods during the heating season. An unoccupied building need not be maintained at the temperature required when occupied but may be operated at some much lower thermostat setting - say 5°C or 10°C (40°F or 50°F). At the lower temperature, a small heating unit will perform adequately and, in most cases, should not need to be so large that an increased capacity electrical service disconnect and panel are needed. The Canadian Electrical Code permits devices of up to 10 kW (which would provide about 34,000 Btu/hr) to be connected on one circuit. Such a heater would not overload the usual 100 amp electrical service. Load shedding devices are available which will permit connection of electrical heaters larger than 10 kW to a 100 amp entrance.

3.2 New Buildings

In new construction, installation details are similar to those described in the first part of this section. Location of the heating appliance should be considered when designing the building, with special attention paid to ease of fuel delivery, fuel storage, back-up heating and chimney location.

3.2.1 Fuel Delivery

Several fuel delivery systems are likely to be established for wood chip fuel, depending on consumer preference and on the supplier's capabilities. All require, or are greatly facilitated by, vehicle access to that part of the building where fuel is to be stored. Bulk

delivery of chips requires that trucks similar to those used for fuel oil delivery be able to come within 10 to 15 metres of the building in order to blow chips into a storage bin. Alternatively, trucks should be able to back up to the building to dump chips into a chute leading directly to a storage bin. If fuel is delivered in bags, the delivery truck should be able to back close to an unloading door.

3.2.2 Fuel Storage

Fuel storage should be close to the stoker or preheater. An auger feed could be arranged from storage to the hopper on the stoker or preheater, or perhaps directly to the furnace. Section 4 discusses storage room construction and ventilation.

3.2.3 Back-up Heating

The basic principals discussed for retrofits in section 3.1 apply. In new construction, high levels of insulation, tight vapour barriers and low heat loss windows and doors are normal. Building design and orientation to make maximum use of passive solar heat gain are also common. For such houses, only a small heating system and modest amounts of space heating fuel are required. A back-up heating device may not be necessary, or if needed, could be very small.

3.2.4 Chimney Location

A chimney should be located inside a heated building rather than being exposed on an outside wall. This keeps the chimney warm. Warm chimneys have good draft and have less creosote condensation when wood is burned. Heat lost by conduction through such a chimney is gained by the building, not lost to the outside.

4. INSTALLATION AND SAFETY

4.1 Space Requirements for Equipment and Fuel Storage

4.1.1 Equipment
4.1.2 Fuel Storage

4.2 Spores and Dust in Fuel Chips

4.3 Safety Code Requirements

4.3.1 Equipment Standards
4.3.2 Installation Standards

4.4 Insurance Considerations

4.4.1 Equipment
4.4.2 Installation

4. INSTALLATION AND SAFETY

4.1 Space Requirements for Equipment and for Fuel Storage

Wood chips and the equipment to burn them require more space than is required for more concentrated fuel. A person considering using wood chip fuel should be aware of space requirements and other factors affecting location of the heating plant.

4.1.1 Equipment

Furnaces and heat distribution systems coupled to stokers are usually no larger than other fuel-burning heating systems. Stoker-fired furnaces can be attached to many types of existing heat distribution systems. Stoker-fired systems can operate safely with less clearance from combustible building components than is required for hand-fired (chunkwood) or gravity-fired (preheater) systems.

The wood chip hopper is the largest component of a wood chip stoker. The equipment under test in Canada and much of that available from Scandinavia has hoppers which contain about a 24 hour supply of chips to an average home on a cold winter's day. This is approximately 0.4 to 0.5 cu m (15 to 18 cu ft). Such a hopper, with feed auger, fire bowl and drive mechanism attached, occupies about the same amount of space as the furnace to which it is coupled. It helps to have space beyond the stoker so that it can be easily decoupled from, and pulled out of, the furnace for servicing. The space for the stoker should be beside, rather than in front of, the furnace. This leaves the loading and ash removal doors free for cleaning and maintenance.

4.1.2 Fuel Storage

The space required for wood chip fuel storage at an individual building depends upon the heat requirement of that building, upon the frequency of fuel delivery, and may also be a function of the form in which the fuel is delivered.

Some chip fuel users may prefer to stockpile roundwood and chip it as required to fill a bin. This may be particularly attractive to some farmers or woodlot owners who have access to roundwood and who have their own chipper and power source. In such cases, chip storage space requirements would be dependent upon how often the operator wanted to chip his wood and fill the bin.

Should chips be delivered in bags rather than in bulk into a bin, some allowance for stacking space should be added to estimates of required storage space. A similar allowance is required for chunk fuel wood storage. Access space is needed and material cannot be piled to fill a space to all corners and to the top. Bulk fuel chips can fill a bin and therefore have the advantage of using storage space most efficiently.

A typical, single-family home in Fredericton uses approximately 600 Imperial gal (2,700 litres) of furnace oil for space heating over a heating season. This amount of oil contains 29,000 kWh (100,000,000 Btu) of potential combustion energy. Hardwood chips at 20% moisture content contain an average potential combustion energy of 1,000 kWh per cubic metre (100,000 Btu per cubic foot). This typical home would require about 29 cubic metres (1,000 cu ft) to store a year's supply of chips. This is a room or bin 3 m (10 ft) on each side or equivalent. During a heating season in Fredericton, which normally has about 4500 Celsius degree day heating seasons, a very cold week could be expected to use approximately 2500 kWh (8,500,000 Btu) of space heating energy. This would require 2.4 cu m (85 cu ft) of hardwood chips which would fit in a 1.3 m (4.4 ft) cube or equivalent. With chip delivery on a weekly, biweekly or even longer basis, fuel bins need not be large, even for the coldest time of the year.

Softwood chips are approximately 20% less dense than hardwood chips (comparing spruce and balsam fir to hard and soft maple mixed), and therefore would apparently require 20% more storage space for equivalent energy. This disregards the effects of the higher potential heating value of the resins contained in the softwood, especially in the bark, which might make the hardwood and softwood chips more nearly equal in heat content per unit of volume.

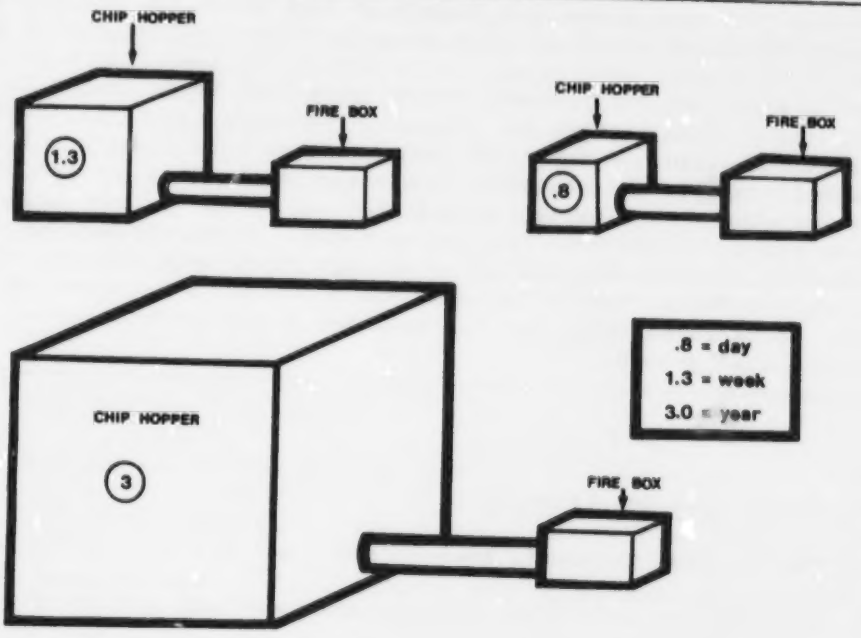


Figure 4.1
Chip Storage Requirements

Approximate chip fuel storage requirement comparison for a house. The units are metres, and must be cubed to obtain storage volume. The day and week hoppers would be for winter. The year's supply would be for a heating season.

4.2 Spores and Dust in Chips

Airborne dust and fungal spores from wood chips can be detrimental to health. Allergies can result from either, although they seem more common as a reaction to spores. Prevention of spore development

can be accomplished by drying the wood. Should spores or dust be present in chips, avoiding their release in a house and preventing their aspiration by those handling the chips is recommended.

One documented case involves a supply of fuel which had heated due to fungi and which contained high amounts of aspergillus spores as a result. Tests done while these chips were being loaded into the stoker hopper from the basement showed very high spore counts in the living space. The handler had allergic reactions (sniffles, runny eyes, asthma) also. A dust mask worn whenever handling the chips prevented the allergic reactions. A sealed chute from outside directly into the stoker hopper allowed filling directly from outside without spore release into the living space. These precautions, plus the wearing of coveralls and ear coverings which were removed before entering the house, have eliminated all problems with contaminated chips. Spore-laden chips can be used, but it is preferable to prevent fungal growth.

4.3 Safety Code Requirements

The Canadian Standards Association (CSA) has developed a set of safety standards for solid-fuel-burning equipment and its installation. The National Building Code incorporates these CSA standards.

4.3.1 Equipment Standards

The CSA Standard "Solid-Fuel Fired Appliances for Residential Use" was prepared very recently and addresses itself to appliances having an input rating of less than 300 kW (1,000,000 Btu/hr) and burning hand-fired or stoker-fired fuel as well as combination systems burning oil and solid fuel.

The standard's specifications contain some flexibility. They are designed to provide guidelines, which, if followed, should result in equipment which will provide heat safely under normal operating conditions as well as remaining safe under less common occurrences such as electrical power failures. Specifications for construction

materials, welds, controls, locations of controls, provisions for venting and combustion air, access openings, and safety limit controls are included. Also included are procedures for testing appliances.

Stokers are specifically discussed in the standards. Because wood-fired stokers are presently uncommon, the specifications are based upon coal stokers. This does not invalidate their applicability to wood stokers, however. The fuel is different but the stokers are similar in mechanical and combustion principles. The specifications which pertain particularly to stokers state that stokers should be designed to prevent overfiring of an appliance in the event of failure of components either of the stoker or the appliance. In addition, each stoker is required to have at least one automatic control to regulate normal operation, a device to maintain a pilot fire when heat is not being called for, and backfire protection in the fuel feed tube.

4.3.2 Installation Standards

The CSA has developed standards for the installation of solid-fuel fired heating appliances, and these standards have been used in the National Building Code. The standards specify clearances required to avoid igniting nearby combustibles and to allow accessibility. They also specify flue types and connections, appliance installation methods, and methods of providing combustion air.

The standards are designed to insure that installations will not ignite combustible building components in the event of equipment component or electrical power failure. They also require a positive manual shut-off to be used when servicing the equipment.

The specifications which apply particularly to stokers require an easily-accessible device for manually stopping the stoker, a device for maintaining a fire for ignition (pilot), and an automatic shut-down in the event of forced combustion air failure. Stokers firing hot water or steam distribution systems require devices to shut down the stoker in the event of low water level or high water or steam temperature (or pressure). Hot air systems require a plenum high-temperature automatic shutoff (high limit control). All the required devices are stock items and are readily available.

Standards specify a minimum of 150 mm (6 in.) clearance around the plenum or water jacket of solid-fuelled furnaces having high limit controls which stop fuel feed. This can be reduced to as little as 50 mm (2 in.) with the proper shielding as detailed in the standard. Hand-fuelled devices require larger clearances because, in the event of emergency shutdown, fuel remains in the combustion chamber. In such circumstances, plenums or jackets can become hotter than normal because there may not be a method of efficiently removing heat from these areas.

4.4 Insurance Considerations

In general, building insurers have come to accept the fact that wood heat is one alternative that is being selected by many people. A very great number of wood-heated buildings are now insured for fire. It is always wise to notify your insurance company when a change in heat source is contemplated, particularly when the change is to wood. If the decision to use wood fuel is firm, it may pay to shop around and choose an insurance company which treats wood-fuelled heating systems most favorably.

4.4.1 Equipment

There are Canadian standards for stoker-fired heating equipment, as detailed in Section 4.3.1. Building codes and insurance underwriters will, in time, require that all equipment to be installed in buildings under their jurisdiction be tested and approved by designated testing facilities. It is advisable for each manufacturer to make himself familiar with the standards and build his equipment with the intent that it would pass the test described in the standard. This precaution should ensure that the equipment will satisfy an insurance company's or building inspector's requirements.

4.4.2 Installation

The CSA and National Building Code standards for approved installations are discussed in detail in Section 4.3.2. Insurance companies normally require installation according to these standards. The standards were prepared to provide a set of safe, uniform specifications for all who wish to install heating devices. Installing according to the standards makes good sense, apart from insurance considerations. The standard for installation of stoker-fired central furnaces should satisfy fire underwriter's requirements. It may be necessary to spend some time with your fire underwriter familiarizing him with the codes.

It is wise for anyone to advise his insurer or prospective insurer specifically what he has in mind in the way of a heating system. The insurer should also be notified of any change in the system. This allows the insurer to react and it protects the insured in the event of a fire. The insurer may require a letter from a municipal or provincial fire safety officer stating that, based upon his inspection, his opinion is that the installation meets safety standards.

5. EQUIPMENT

5.1 Combustion of Wood Chips

5.2 Stoker Equipment Description

5.2.1 Stoker Fired Systems: Simple Stokers
- (a) Hopper and Anti-bridging Device
- (b) Fire Stop
- (c) Overfeed and Underfeed Stokers
- (d) Combustion Air
- (e) Firing Rate
- (f) Controls
- (g) Combustion Grate

5.2.2 Stoker Fired Systems: Precombustion Chamber

5.3 Stoker Operation and Maintenance
- (a) Lighting the Fire
- (b) Routine Inspection
- (c) Ash Removal and Cleaning

5.4 Preheater Equipment Description
- (a) Hopper
- (b) Combustion Chamber
- (c) Refractory Tunnel
- (d) Control
- (e) Heat Output Adjustment

5.5 Preheater Operation
- (a) Lighting the Fire
- (b) Routine Fuelling
- (c) Maintenance

5.6 Performance Analysis
- (a) Smoke Test
- (b) Draft Measurement
- (c) Carbon Dioxide Measurement
- (d) Stack Temperature
- (e) Moisture Content
- (f) Determining Combustion Efficiency

5.7 Troubleshooting

5. EQUIPMENT

5.1 Combustion of Wood Chips

Much of the useful fuel energy in wood is given off as gases. A properly designed and operated burner is required if the gases are to be burned efficiently. If the gases are not burned, they either condense inside the chimney to form highly combustible creosote, or they escape to contribute to air pollution. Well-designed wood chip burners consume their fuel in a very hot fire and are able to burn these gases. This results in high combustion efficiency and relatively clean burning with little or no creosote production.

5.2 Stoker Equipment Description

5.2.1 Stoker Fired Systems: Direct-coupled Stokers

Wood chip fuelled, automatically stoked heating systems consist of a stoker and a boiler or hot air furnace.

The fire in a stoker-fired plant is located inside the combustion chamber of the furnace and is controlled in much the same way as is an oil or gas fuelled system. When heat is needed, a thermostatic control starts the stoker motor so that fuel is fed to the fire and a hot fire develops. Once the thermostat is satisfied, the stoker shuts off and the fire dies down quickly. Since some time may pass before heat is again required, a small time-clock driven control is used with some stokers to turn the stoker on briefly and at regular intervals to maintain a smoldering fire. Other manufacturers offer stokers which operate

at a very slow speed continuously but which speed up in response to a requirement for heat. Both cases are similar to a pilot light in gas fired appliances.

(a) Hopper and Anti-bridging Device

Currently available stokers consist of a bin or hopper having a capacity of about 0.5 cubic metres (18 cubic feet) or larger, a chip feeding mechanism and a combustion section. An electric motor of about 0.2 kW ($\frac{1}{4}$ hp) is arranged to drive a screw conveyor or auger by means of a system of V-belts, chain drives or a gear box. The auger is located in the bottom of the hopper so that when it turns, it takes chips from the hopper and towards the boiler or furnace through a pipe. The hopper is usually equipped with either a system of plates on the bottom inside surface which jostle the chips in the bin when the auger operates, or with a slowly rotating "tree" running horizontally through the middle of the hopper. The tree consists of a shaft to which several arms have been attached. When the shaft rotates, the arms agitate the chips. The purpose of either device is to ensure that the chips do not hang up or bridge inside the hopper. Chips, because of their shape and size, do not always settle readily in the hopper without such agitation.

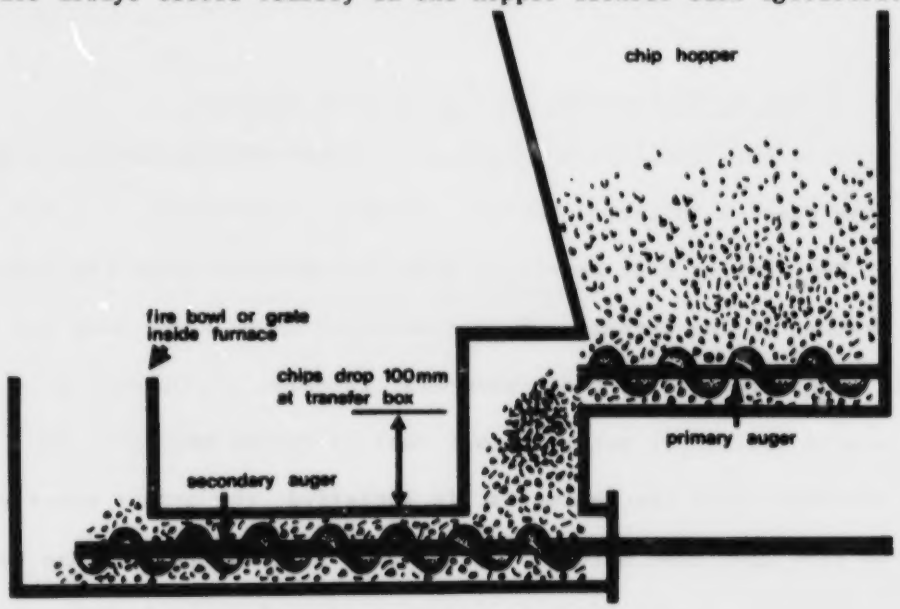


Figure 5.1
Transfer Box

A transfer box serves as a fire stop in some stoker designs. Fire burning back along chips in the lower auger can not jump up to the second auger and so into the hopper.

(b) Fire Stop

Chips move along the auger and may pass directly into the combustion chamber. In some designs, they fall through a distance of about 100 mm (4 inches) in a transfer box to a second auger which then takes them to the combustion chamber. The purpose of the transfer box is to prevent fire from burning back along the auger and into the main fuel hopper. Should fire burn back to the transfer box it cannot jump to the first auger and thence to the hopper. Stokers using only one auger are fitted with a water quench system. A thermostatically operated valve dumps either domestic water or water from a separate 4 litre (1 gal) reservoir and floods the auger which extinguishes the fire.

(c) Overfeed and Underfeed Stokers

Once the chips reach the combustion chamber, they may drop down onto a grate where they burn; this is an overfeed stoker. Alternatively, the chips may be fed under the fire where they then are pushed up into the fire by subsequent chips; this is an underfeed system. In small burners currently available, underfeed systems tend to burn fuel more efficiently than do present overfeed systems. There are at least two possible reasons for this. Gases given off by the chips as they start to heat and burn in the underfeed system must pass through the hotter, pyrolysis section of the fire thus increasing the likelihood of their combustion. Also, small particles are less likely to become airborne before burning in the underfeed system. Once airborne, they are in a cooler environment and are less likely to burn well.

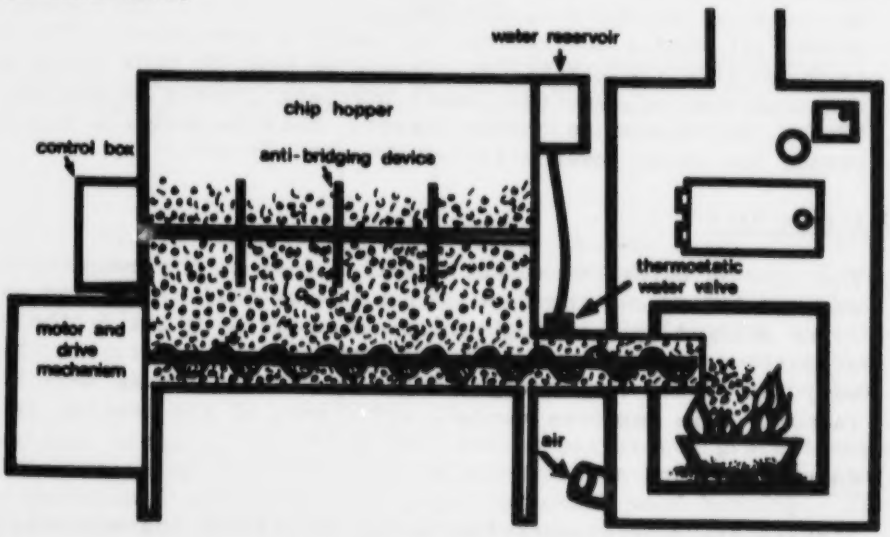


Figure 5.2
Overfeed Stoker

Typical arrangement of an overfeed stoker. The chips fall down into the fire. Note the use of an anti-bridging tree in the chip hopper and of a water tank and automatic valve back-fire extinguisher.

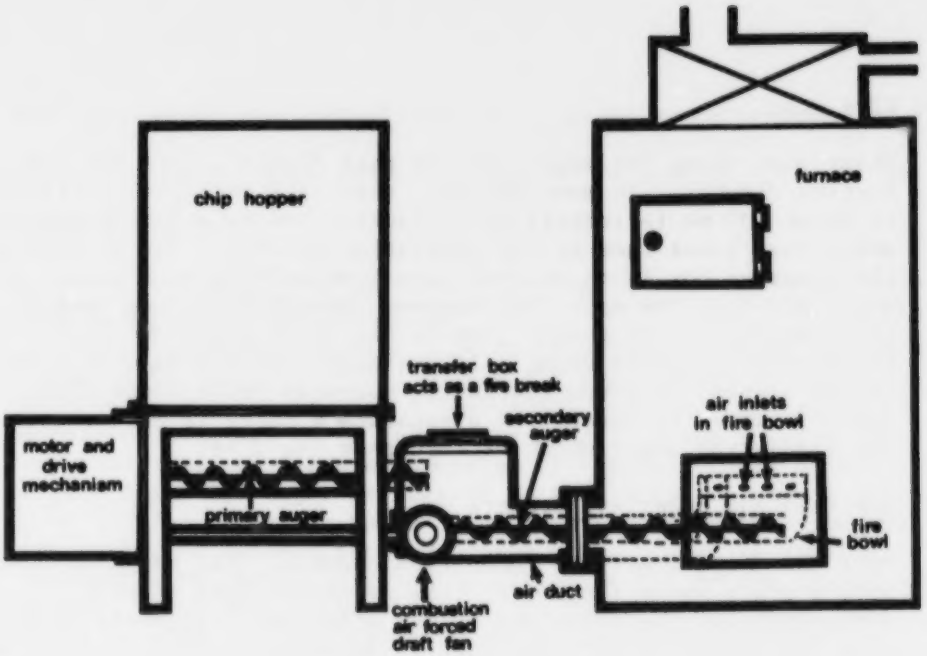


Figure 5.3
Underfeed Stoker

An underfeed stoker. Fresh chips are pushed up under the fire by the auger. Note the use of a transfer box to prevent fire from burning back into the main fuel hopper.

(d) Combustion Air

The more efficient stokers are fitted with a small blower which is connected by ducts to the combustion section. This ensures a proper air supply and mixing for complete combustion. The blower is wired into the electrical circuit so that it runs along with the stoker motor. Current small overfeed stokers do not use a blower, but depend on chimney draft. This is probably another reason for their lower efficiency.

(e) Firing Rate

The rate at which the stoker supplies fuel to the combustion section determines the heat output (kW or Btu/hr) and can usually be changed to suit a given installation by altering the size of pulleys in the drive from the motor to the auger. In this way, the stoker can be adjusted to operate at a high capacity factor. This improves overall efficiency of the heating system.

(f) Controls

Stokers are always controlled using electrical thermostats. These turn the stoker on and off in response to requirements for heat. When heat is not required, some time may elapse before the thermostat calls for more heat. The fire could die out if some small quantity of fuel were not added. A timer fitted to the stoker turns the stoker on for a few seconds at suitable intervals, adding just enough fuel to maintain fire.

(g) Combustion Grate

The combustion section of the stoker is located centrally within the combustion chamber of the boiler or furnace. It has to perform several functions. It must:

- receive incoming, fresh chips for combustion,
- distribute the combustion air from the blower in the case of underfeed stokers, and
- contain the stand-by, maintenance fire.

The combustion section of underfeed stokers is shaped like an elongated bowl. Its rim contains air inlet holes. Fuel enters at the bottom of one end of the bowl and rises in the bowl as the stoker runs.

Figure 5.4
Underfeed Grate

Details of an underfeed stoker grate. The chips enter along the auger and start burning almost as soon as they are in the grate. Air blows over the fire from openings around the grate. Ashes and much incombustible foreign material such as stones and nails slide up the ramp and are discharged at the left hand opening.

Meanwhile, air is blown through the inlets in such a way that it is directed inwards towards the fuel from around the perimeter of the bowl. The air flow blows ashes off the fuel pile in the bowl but is not forceful enough to remove burning chips. The incoming air also serves to cool the upper portion of the combustion bowl where the heat is the greatest. This helps to protect the metal of the bowl.

In overfeed stokers, the chips fall onto a perforated grate located near the bottom of the combustion chamber of the boiler or furnace. It is positioned similarly to a grate for chunk wood burning. Air is drawn into the combustion chamber through an inlet near the bottom of the chamber and flows up through the grate. Draft is created by the chimney. In current designs, no supplementary air supply is used. For proper operation, this system requires dry fuel and a well-baffled combustion chamber to force the gases to circulate back down to the fire for more complete combustion.

5.2.2 Stoker Fired Systems: Precombustion Chamber

Some manufacturers offer stokers which are coupled to a precombustion chamber. Such units are able to continuously burn wet (100% moisture content and above) fuels since a high temperature is maintained within the precombustion chamber. The equipment is similar to the overfeed and underfeed stokers already described. The principal difference is that instead of using a combustion bowl or grate located inside the boiler or furnace combustion chamber, the fire burns in a well-insulated, specially designed chamber placed outside the boiler.

The precombustion chamber is a cylinder standing on end and has a well-insulated, gasketed, tightly fitting lid on top. The lid provides access for igniting the fire and for removal of ash.

The precombustion chamber is lined with refractory fire brick capable of withstanding temperatures in excess of 1200°C. In operation, this firebrick glows bright red-orange yet its insulating properties are such that the outer surfaces of the precombustion chamber are safe to handle.

A blower mounted on the side of the precombustion chamber supplies primary air and causes sufficient turbulence to obtain good combustion and a hot fire. Flames and hot gases leave the chamber through a short, insulated pipe which connects to the combustion chamber of the boiler or furnace. An air inlet in this pipe permits secondary air to be added so gases will be burned completely. Little or no visible flame reaches the normal boiler/furnace combustion chamber.

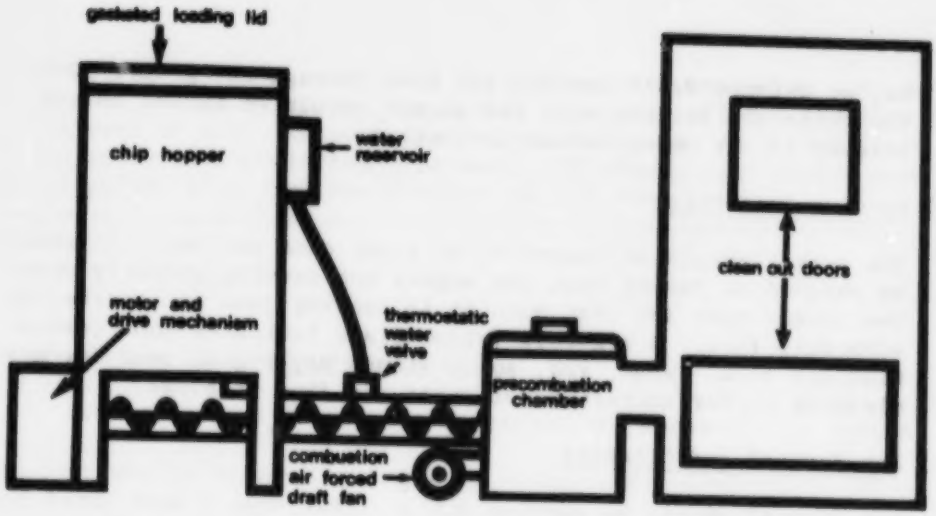


Figure 5.5
Precombustion Stoker

Stoker fed precombustion chamber system. Chips are burned in the chamber to the left of the boiler. Note the water back-fire extinguishing system.

5.3 Stoker Operation and Maintenance

Operation and routine maintenance of a wood chip stoker system is simple and requires very little of the operator's time. When the stoker is turned off for maintenance the fire quickly dies and few live coals remain. Shut-down times for maintenance are therefore usually short, with no interruption to building heat.

(a) Lighting the Fire

The stoker should be turned on and allowed to run until a fist-sized pile of chips has accumulated in the fire bowl, precombustion chamber or on the grate. The stoker should then be turned off.

The chips can be set on fire quickly and safely by pouring 25 ml (1 ounce) of barbecue lighter fluid on the pile, letting it soak in briefly and then igniting it with a match. Alternatively, a small propane torch flame can be directed at the lower edge of the chip pile until the chips are glowing. With dry chips, a sheet of crumpled newspaper can be tucked into the pile and set afire with a match. Chips will begin to glow and emit visible smoke. They will burst into flame after the blower is turned

on, or chimney draft induces air flow through the grate. Once the chips are burning well the stoker should be turned on and allowed to run under automatic control.

(b) Routine Inspection

The stoker should be inspected at least once per day. It should be checked to ensure that the augers are turning properly when the stoker runs and that nothing is causing jams or interfering with chip flow. A vigorous yellow flame indicates good combustion air flow. Weak, red, sooty flames may signal need for grate cleaning or for correction of other air flow problems.

(c) Ash Removal and Cleaning

Ash removal should be carried out at least once a week until the operator becomes familiar with the equipment. Some appliances have easily-removed ash drawers into which ashes fall. Automatic ash disposal equipment is offered as an option by at least one manufacturer of an underfeed stoker system.

Ashes should be placed in metal pans or garbage cans for disposal since they may contain live coals.

The smoke passages, heat exchanger surfaces and smoke pipes should be inspected at least once a month, and cleaned as necessary. A permanently-installed flue gas thermometer will help the operator know when cleaning is necessary. Higher than usual readings indicate dirty heat exchangers. Equipment designed for wood burning should have access openings to permit easy inspection and cleaning. Wet chips (in some stoker designs), poor combustion air flow, or long idling periods can produce soot which can build up a 25 mm (1 inch) layer on various surfaces in a month or so. Such a layer acts as an insulator and reduces transfer of heat. Additional cleaning will probably be required when any of these have occurred.

An underfeed stoker may need to have its bowl cleaned periodically. Some manufacturers specify a weekly cleaning schedule while operating experience with one design has shown that a monthly or bi-monthly schedule is acceptable. The reasons for cleaning the bowl are:

- accumulation of non-combustible debris (sand, small stones, nails) in the bottom of the bowl abrades the auger as it rotates in the bowl;

- large ash particles tend to block openings in the bowl through which combustion air enters;

- accumulations of char can cause a jam by preventing fresh chips from flowing into the bowl.

Cleaning the bowl takes from 5 to 30 minutes depending upon design. During cleaning, the stoker is turned off and the fire is allowed to die. In some designs, cleaning can be accomplished by reaching through the fire door. In others, the stoker must be pulled away from the furnace and the bowl removed.

5.4 Preheater Equipment Description

Wood chip fuelled preheater systems are mechanically simple since they use no motor-driven augers or blowers. Combustion takes place primarily in the preheater and partially in the boiler or furnace with which it is used. Preheaters consist of a hopper, a combustion chamber and a refractory tunnel leading to the attached furnace.

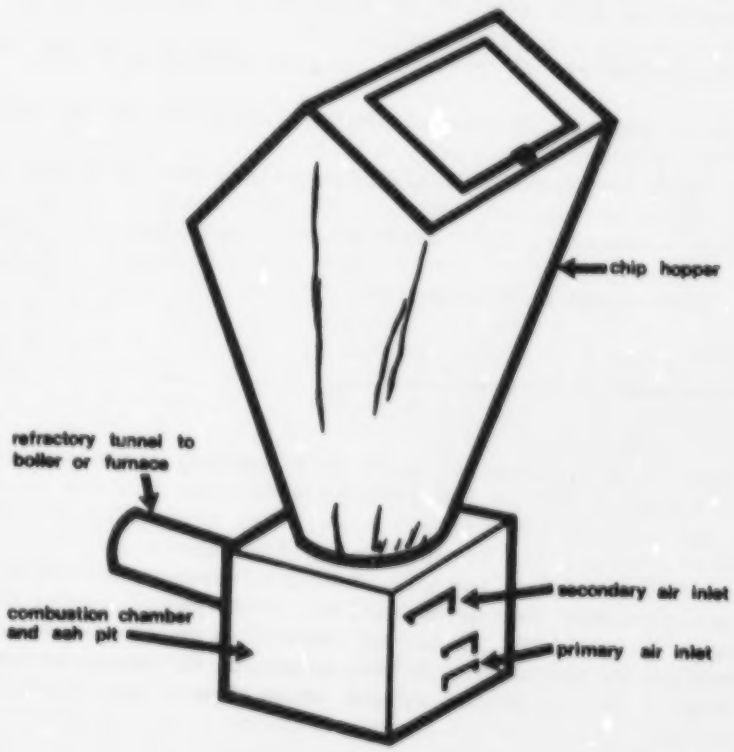


Figure 5.6
Preheater - General

General arrangement of a chip burning preheater.

In operation, wood chips and sawdust in the hopper move downwards by gravity and, at the bottom of the hopper, come into contact with a hot U-shaped arch (see illustration). Here they are dried and heated and dropped onto a perforated grate where they start to produce gases. The gases begin to burn in the grate region and refractory tunnel where they mix with additional air. Combustion is completed in the furnace combustion chamber. Daily attention is required for refuelling and ash removal.

The preheater output is controlled thermostatically, either with purely mechanical linkages between the control thermostat and the draft regulating dampers or with electrical controls. The fuel burned must be above 40% moisture content to prevent too-rapid burning of the wood chips in the arch region. This could establish a fire in the main hopper. As long as the hopper is tightly sealed, any fire there is safely contained. However, the consequence of burnback is likely to be loss of fire in the combustion chamber.

(a) Hopper

The hopper on a residential wood chip burning preheater is shaped like a funnel 800 mm (30 inches) wide near the top at its widest and 1300 mm (50 inches) high. The hopper is fitted with a gasketed, hinged lid through which fuel chips are loaded. It is mounted directly on top of a box-like combustion chamber. As chips are consumed during operation, fresh chips settle down in the hopper by gravity. Since no mechanism exists to ensure uniform flow of the chips, it is necessary to keep the hopper quite full. This provides weight which forces the fuel down.

(b) Combustion Chamber

The combustion chamber is a refractory lined, cast or welded steel box. It contains an arch made of refractory material or cast stainless steel above the grate. There is an ash pit beneath the grate. Air inlets fitted with dampers are on the front of the chamber.

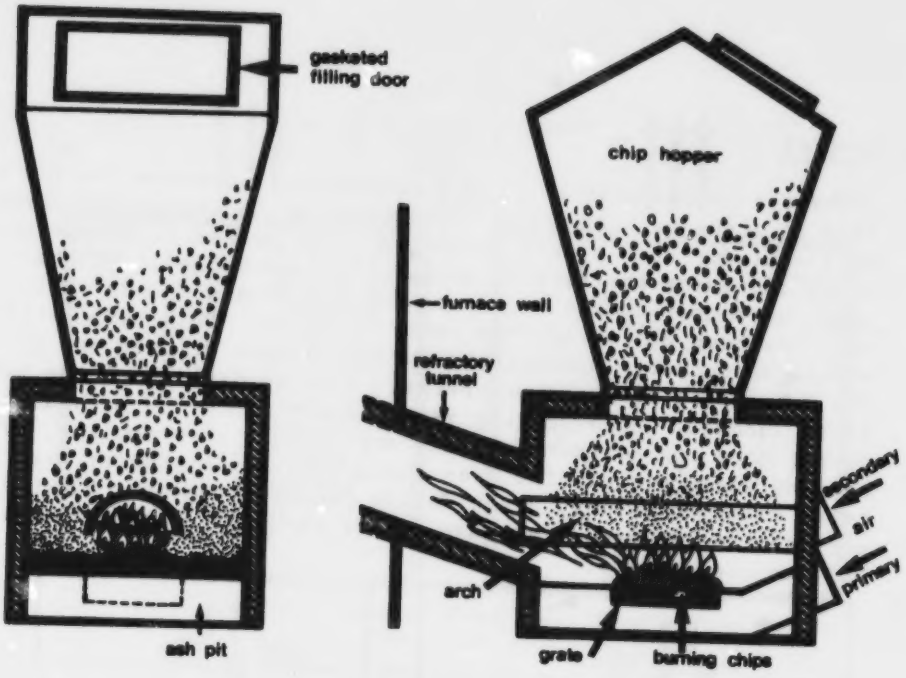


Figure 5.7
Preheater - Details

Preheater internal details showing the chip dividing arch in relation to the grate and hopper.

In operation, the chips in the hopper settle down onto the arch which is very hot. Chips in contact with the arch dry quickly and start to smolder, although sufficient air is not available for rapid, flaming combustion. The smoldering chips gradually slide down over the arch and fall onto the grate. Here, in the presence of primary air supplied to the grate, they burn rapidly. The heat from this combustion maintains the arch at high temperature. Ashes fall through the grate and are collected in the ash pit. Heat output is controlled by a thermostat on the boiler or furnace which regulates the primary air damper. Secondary air supply is adjusted manually. It is added either just underneath the arch or in the refractory pipe leading from the combustion chamber.

(c) Refractory Tunnel

The refractory tunnel is cast on site, allowing the preheater to be adapted to many different furnaces and boilers. It is made from special heat resistant materials and conducts hot gases from the preheater to the combustion chamber of the furnace. The gases continue to burn in the tunnel, so it is really an extension of the preheater combustion chamber. The tunnel is about 300 mm (12 inches) long and 125 mm (5 inches) inside diameter and must slope upwards from the preheater at about 20° from the horizontal. The tunnel is brittle and must remain air-tight. Once the preheater has been positioned it should be securely fastened to the floor so that it cannot move and crack the tunnel.

(d) Control

Preheater installations using a mechanical thermostat have a set of wire linkages connecting the thermostat to combustion dampers. On a call for heat by the thermostat, the preheater damper opens which increases the rate at which chips are burned. At the same time the damper on the boiler or furnace closes. When sufficient heat has been delivered, the reverse occurs. This reduces the preheater output. Opening the furnace damper dilutes and cools the hot gasses from the preheater. This tends to cool the boiler or furnace. Such cooling is necessary since the preheater output does not decrease rapidly and without such cooling, overheating would occur. The open furnace or boiler damper also helps maintain chimney draft during low heat output. Electrically controlled preheaters use motors to operate the preheater and furnace dampers.

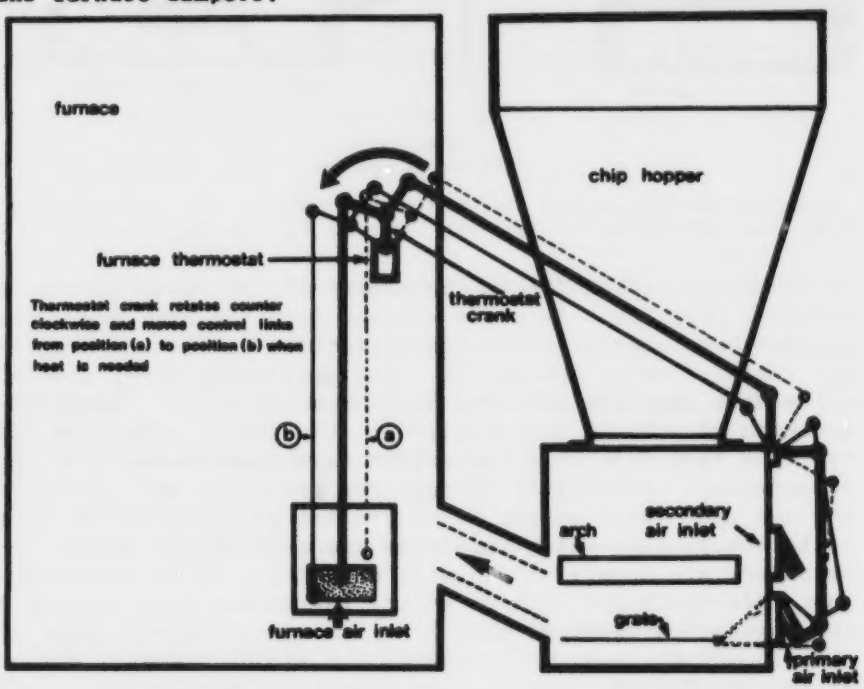


Figure 5.8
Preheater - Mechanical Controls

Mechanical damper control system used with preheaters. The light lines show the control position for maximum heat, and the dotted lines show the position when heat is not required.

(e) Heat Output Adjustment

Fine control of the thermal output from a preheater is not possible, although some manufacturers offer ways to achieve a measure of control. Two systems exist, and both use grate adjustments. In one, the height of the grate can be varied. Raising the grate decreases the gap available for chips to pass from the arch to the grate. This retards chip flow and reduces output. Lowering the grate increases preheater output.

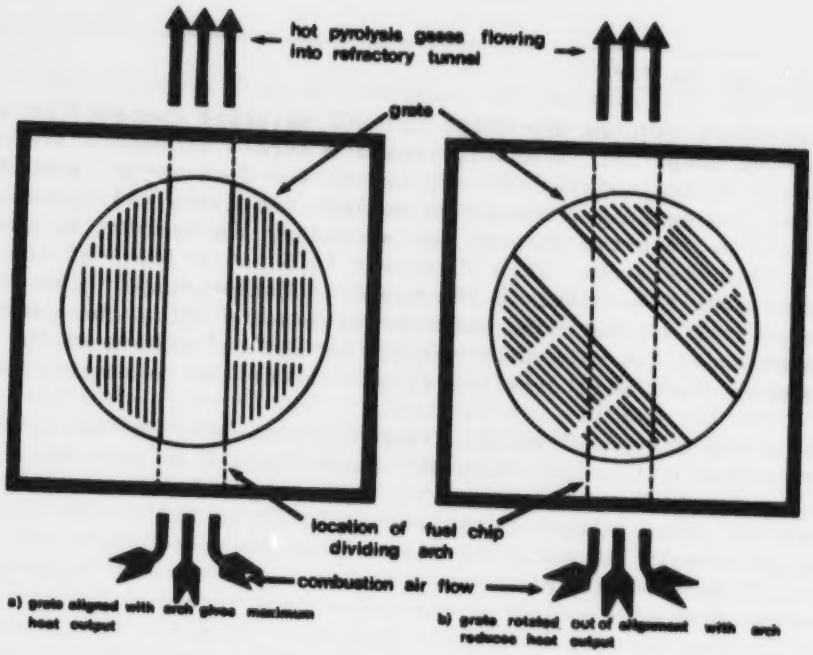

hot pyrolysis gases flowing into refractory tunnel
grate
location of fuel chip dividing arch
combustion air flow
a) grate aligned with arch gives maximum heat output
b) grate rotated out of alignment with arch reduces heat output

Figure 5.9
Preheater Grates - Adjustment

Maximum preheater output may be adjusted with some makes by rotating the grate. The system is explained in the text.

A second system features a circular grate having an unperforated control area along a diameter. With the grate rotated so the unperforated diameter is aligned with the arch, all primary air (which passes through the grate) must also pass through the chips that have fallen off the arch. As the grate is rotated progressively further (up to 90 degrees at most) more chips fall onto the unperforated area where, deprived of primary air, they burn less rapidly. At the same time, air passes through grate openings now located under the arch. This mingles directly with combustion gases and so behaves more like secondary than primary air. The combined effect is to reduce output of the preheater.

5.5 Preheater Operation and Maintenance

Currently available preheaters have few moving parts, so little mechanical maintenance is required. Refuelling, grate cleaning and ash removal are required at frequent intervals. Operation requires some skill.

(a) Lighting the Fire

Preheaters require dry chips (15-20% moisture content) to start burning properly. A small, separate supply of such starting fuel should be kept available. To begin, the fuel hopper should be empty. A newspaper should be rolled (not crumpled) loosely and should be inserted through the secondary air opening so that it is under the arch. Then 50 litres (1.5 cubic feet) of the dry chips should be added to the hopper. The newspaper prevents the chips from sliding down over the arch and filling the combustion space under it. The paper should be ignited with a match. Chimney draft will draw the flame towards the refractory tunnel.

While the fire is developing and the preheater is coming up to temperature, the secondary air damper should be kept open and the primary air damper closed. Once the combustion zone has reached normal temperature (around 500°C or 950°F) the primary damper should be opened slowly. Then the secondary damper should be slowly closed while making sure that the flame is coming from the outlet of the refractory tunnel. This is done by looking briefly inside the furnace. Finally, the secondary air damper can be fully closed. The hopper should then be filled with normal fuel.

The described procedure avoids causing unstable combustion. This can occur when a mixture of combustible gases, hot enough to burn but lacking necessary air, is suddenly mixed with sufficient air. The gas ignites and burns very rapidly until it is consumed. This is a form of limited explosion called a "puff".

In the preheater, a particular set of conditions causes puffing. While the preheater and chips are cold, water vapour formed during combustion condenses and leaves the remaining gases concentrated. If these concentrated gases are mixed with primary air, they will puff. As combustion continues, a rich mixture will soon develop again. This will cause another puff. The sequence will continue unless controlled. Puffing is not necessarily dangerous, but can result in smoke and burning chips being forced out of dampers and into the building.

(b) Routine Fuelling

In loading the hopper, the chips should be allowed to tumble in freely. No attempt should be made to pack them or compress them in any way. Packed chips tend to bridge or hang up in the hopper causing the fire to die down. It may go completely out from lack of fuel. If it is not out and chips become dislodged and fall on the arch, conditions can be established which will lead to puffing. Routine fuelling is required twice daily in current residential-sized preheaters.

(c) Maintenance

Char and clinkers form at the edges of the arch and need to be removed once or twice daily. If these are not removed, they prevent chips from falling around and under the arch, decreasing preheater output. Ash must be cleaned from the grate daily. This maintains air flow through the grate and the space between the grate and arch.

Combustion chamber conditions can be judged by observing the flame leaving the refractory tunnel. When the preheater is operating well, the flame should be clearly visible. Healthy flame is light in colour and extends well into the boiler or furnace combustion chamber. Intermittent, broken and short flames indicate that grate and arch cleaning is required. A dark red, smoky flame also indicates that the fire is not receiving sufficient air for good combustion. This may suggest grate cleaning is needed, or that more secondary air is required. If grates are clean, the secondary air damper should be gradually opened until a satisfactory setting is found.

5.6 Performance Analysis

Combustion efficiency is the percentage of the potential energy in a fuel that is being produced as it is burned. Combustion efficiency contributes to the overall thermal efficiency of the appliance. Overall efficiency is affected by combustion efficiency and effectiveness of the heat exchanger. Overall thermal efficiency is the percentage of the potential energy in the fuel which heats the building. Performance analysis measures combustion efficiency and indicates ways to improve it.

Burner servicemen normally carry a set of instruments which enable them to measure combustion efficiency. The instruments include a smoke tester, draft gauge, carbon dioxide analyzer, and stack thermometer. They are to used to perform a stack-loss, steady-state test.

Before the test, the stoker is allowed to run for about ten minutes. Setting a room thermostat to a high enough temperature or closing a special test switch will cause the stoker to run. This warm-up permits the combustion chamber and chimney to reach normal operating conditions.

(a) Smoke Test

The smoke test uses an instrument which draws a specified quantity of exhaust gas through special filter paper. The darkness of the resulting spot on the paper is compared with a standard scale ranging from 0 (no visible spot at all) to 9 (totally black). High smoke numbers indicate poor combustion and suggest either too great a wood chip fuel feed rate or insufficient air supply. Either can be corrected by adjustment or repair. It is possible to obtain smoke numbers in the range of 0 to 2 with well-adjusted wood chip burning equipment.

(b) Draft Measurement

The draft gauge is used to measure the pressure difference between air in the room outside the combustion chamber and the gases inside the combustion chamber. This pressure is known as the over-fire draft and should be specified by the equipment manufacturer. It is usually in the range of -0.25 Pa to -5.0 Pa (-0.01 inches of water to -0.02 inches of water). The negative pressure shows that there is a slight vacuum in the combustion chamber. The vacuum prevents combustion gases from leaking out of the furnace or boiler. Draft is changed by adjusting the barometric damper on the smoke pipe. After adjustment, the smoke number should be rechecked and combustion air inlets adjusted if necessary. The process should be repeated until best possible conditions occur.

(c) Carbon Dioxide Measurement

The gas analyzer takes a sample of exhaust gas from the same point as for the smoke test, and then absorbs any carbon dioxide (CO_2) in a solution of potassium hydroxide. Absorbing the CO_2 causes the solution to rise in a calibrated tube. This gives the percentage of CO_2 in the stack gas.

If too little combustion air is supplied, carbon monoxide (CO) gas is formed rather than CO_2 and a low CO_2 reading results. If too much air is supplied, stack gases are diluted so that the proportion of CO_2 decreases, also giving a low reading. The serviceman's job is to obtain the highest CO_2 reading at the lowest smoke number.

(d) Stack Temperature

A thermometer capable of indicating temperatures in the 100°C to 400°C (200°F to 800°F) range is used to measure exhaust gas temperature where the smoke sample was obtained. The stack gas temperature should be low since heat contained in the gas is lost into the atmosphere. High stack temperatures can indicate heat exchange surfaces which should be cleaned. Stack temperatures of 90°C to 150°C (200°F to 300°F) give good efficiency. They also maintain adequate chimney draft. Lower temperatures may require installation of a draft inducer in the stack.

(e) Moisture Content

The moisture content of the chips burned during testing affects combustion efficiency. Moisture content determinations require an oven for drying, a balance for weighing and a container to hold a sample of chips. Several chip samples of about 15 grams ($\frac{1}{2}$ oz each) are recommended. They should be taken from the auger or from the bulk of chips in the hopper. Chips from the very top of the hopper may be affected by the humidity of the air in the boiler room, and therefore may not represent the bulk moisture content.

Moisture content is calculated using the method described in Section 7.1.

(f) Determining Combustion Efficiency

Test values of CO_2, stack gas temperature and moisture content allow the curves shown in Appendix III to be used to find efficiency.

Suppose the following readings had been made:

CO_2 = 9-3/4%
Stack Temperature = 150°C
Moisture Content - 25% (dry basis)

The graph in Figure III.1 shows 9-3/4% CO_2 near the middle on the left side. Reading across from 9 3/4% to the curve and then down to the bottom, one finds that the excess air is about 100%. Next use the curves for 25% moisture content wood (Figure III.3) and on the left side find the temperature (150°C). Move over to the right until the diagonal line for 100% excess air is reached. Then read down to find a combustion efficiency of 80%.

5.7 Troubleshooting

Chip burning equipment is simple and reliable. When breakdowns do occur, they can often be repaired by the operator at least so heat can be restored until a serviceman can visit. The first obvious sign of trouble in any heating system is a cool building and/or lack of domestic hot water. Some problems and suggested corrections are contained in the following list.

TROUBLE DIAGNOSIS AND REPAIR

Condition	Possible Cause	Suggested Corrections
1. House cool	Thermostat malfunction	Check thermostat
	Fire out	Check cause - see 2 or 3
	Poor fire	Check cause - see 4 or 5
	Dirty heat exchanger	Clean exchanger
2. Fire out - stoker	Out of fuel!?	-
	Fuse blown	Replace fuse. Call for service if fuse blows again
	Power failure	Restart stoker. Relight it if necessary
	Timer incorrectly set	Reset timer to run stoker longer
	Timer faulty	Repair/replace
	Drive belt broken	Replace
	Shear pin broken or torque limiter slipping	Clear jam. Repair or replace equipment if necessary. Reversing auger often clears jam
	High limit switch thrown	Check blower or water pump
	Stack ignition failure switch thrown	Reset, relight stoker
	Change in fuel density or MC	Reset timer to run stoker longer and/or increase stoker speed
3. Fire out - preheater	Out of fuel!?	-
	Chips bridged in hopper	Clear by poking
	Chip jam at arch	Clear arch
	Grate plugged	Clean grate and ashpit
4. Poor fire - stoker	Inadequate air supply	a) Clean airways b) Clean blower c) Lubricate blower
	Inadequate fuel supply	a) Clear auger inlet in hopper b) Retension drive belt
	High moisture content fuel	Increased air supply and fuel flow may compensate, If not, replace with dry chips
	Low density chips	Increase stoker feed speed
5. Poor Fire - preheater	Char on arch	Clean arch
	Clogged grates	Clean grates, remove ashes
	Inadequate air supply	Check and adjust damper controls

6. Stoker Jam	Oversize chips or foreign object in auger	Reverse auger briefly or remove auger to clear jam
	Char and grit accumulation in grate	Clean grate
	Worn or bent auger	Install replacement auger
7. Smoke in House	Embers in open ash container	Store fresh ashes outside
	Low draft	Adjust draft regulator, clean smoke pipe and chimney
	Clogged forced combustion air grate	Clean grate
	Hole in firebox or heat exchanger	Repair or replace
8. Flue Thermometer reading high	Dirty heat exchanger	Clean
	Excessive fuel supply	Reduce stoker speed or adjust preheater grate

6. WOOD CHIP FUEL SUPPLY

6.1 Harvesting Systems: Pre-Commercial Thinnings

6.1.1 System 1: Fully Manual
6.1.2 System 2: Manual with Logging Winch
6.1.3 System 3: Manual with Winch and Forwarder

6.2 Harvesting Systems: Commercial Thinnings

6.2.1 System 1: Whole Tree
6.2.2 System 2: Shortwood/Winch
6.2.3 System 3: Shortwood /Tree-length
6.2.4 System 4: Full Tree
6.2.5 System 5: Shortwood/Forwarder
6.2.6 System 6: Tree Length

6.3 Harvesting Systems: Clear-Cut or Final Cut

6.4 Harvesting Systems: Clean-Up Operations

6.5 Farm Tractor Mounted Chipper

6.6 Drying

6.6.1 General Requirements for Fuel Wood Drying
6.6.2 Roundwood Drying
6.6.3 Chip Drying

6.7 Supply Organizational Possibilities

6. WOOD CHIP FUEL SUPPLY

Wood chip consumption can have a desirable impact on forest management by providing a market for "weed" species, thinnings and limbs that have no commercial value as fiber or chunk firewood. This chapter is an introduction to equipment and systems suitable for chip harvesting and processing in a woodlot.

6.1 Harvesting Systems: Pre-Commercial Thinnings

The purpose of pre-commercial thinning is to improve the residual stand by reducing competition and removing undesirable species. It is advisable to keep the damage to the residual stand as low as possible. The harvested trees are preferably cut with a cleaning saw, a light chainsaw or with hand tools. Directional felling should be used wherever possible to facilitate bunching and transporting of cut trees.

Figure 6.1
Rough Limbing

Should limbing of the occasional tree or tree segment be required, then rough limbing is recommended. This increases the amount of chips produced per tree. Make sure the chipper infeed system can handle rough limbed pieces before adopting this practice.

6.1.1 System 1: Fully Manual

This system requires tractor trails to be laid out 30 - 40 metres (100 - 130 feet) apart. Chipping takes place along the tractor trails. The cleaning saw operator fells the trees using directional felling while another worker manually brings the trees to the trail side. The chipper operator feeds the trees, butt first, into the chipper.

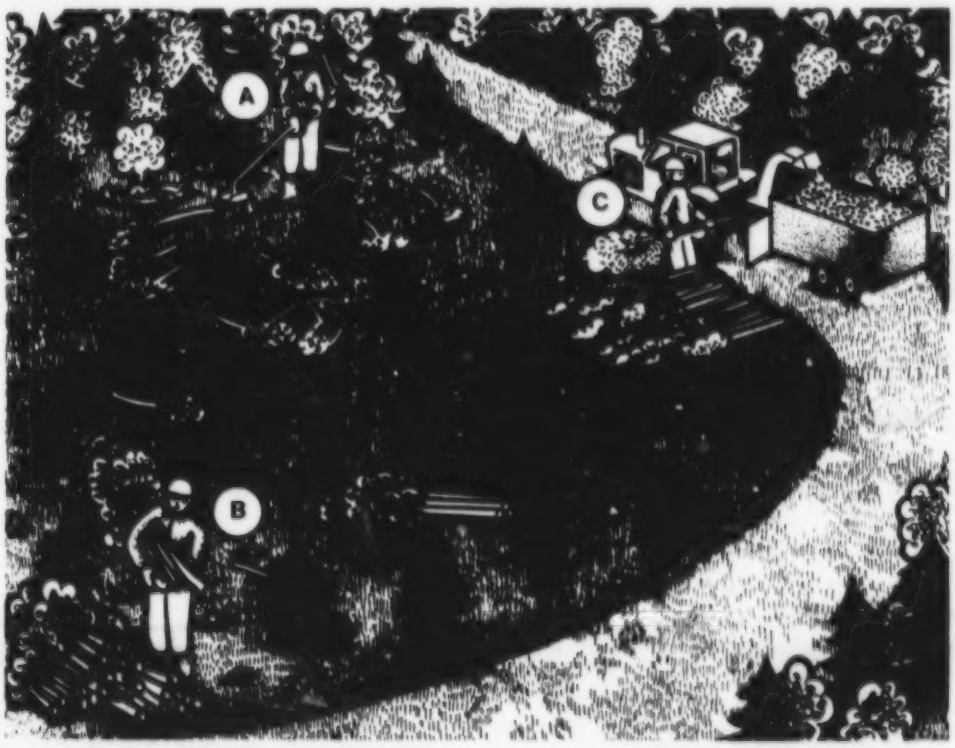


Figure 6.2
Manual Harvesting System

A. Pre-commercial thinning with a clearing saw and using directed felling.
B. Manual bunching of trees with butts facing the tractor trail. Note that the bunches should be perpendicular to the feeder opening on the chipper.
C. Chipping and transporting of the chips to the consumer.

6.1.2 System 2: Manual with Logging Winch

This system requires tractor trails to be laid out 40 - 60 metres (130 - 200 feet) apart. Chipping takes place along the tractor trails. The cleaning saw operator fells the trees using directional felling and another worker brings the trees together in bunches. These bunches are then winched to the trail using a skidpan and a light winch with radio or manual remote control. The chipper operator feeds the trees, butt first, into the chipper.

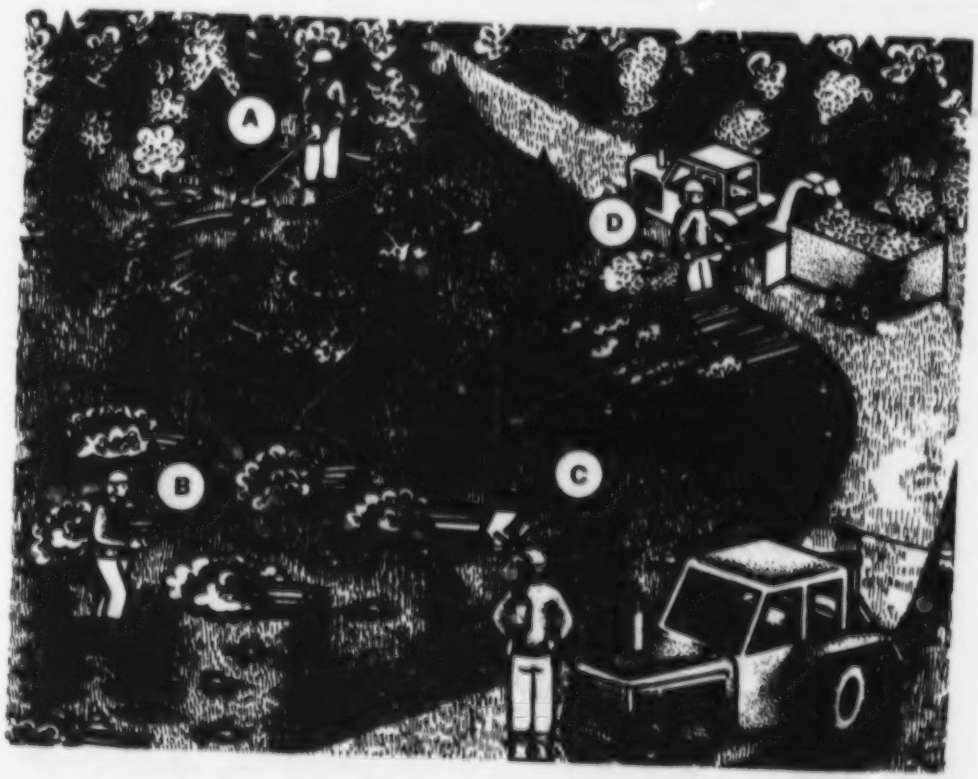


Figure 6.3
Manual Harvesting Using a Winch

A. Pre-commercial thinning with a clearing saw and using directed felling.
B. Manual bunching in the stand with butts facing the tractor trail.
C. Winching of bunches to tractor trail using a skid pan. The cone shaped skid pan reduces friction and the chances for the load to get stuck.
D. Chipping and transporting of chips to the consumer.

6.1.3 System 3: Manual with Winch and Forwarder

This system requires tractor trails to be laid out 40 - 60 metres (130 - 200 feet) apart. Chipping is done along a road, on a landing or at the place of consumption. The cleaning saw operator fells the trees using directional felling while another worker brings the trees together in bunches with the butts facing the tractor trail. The tractor operator brings the bunches to the trail and loads them on his trailer using a wire crane loader with remote manual or radio control. The loaded trailer is then brought to a road, landing or the point of consumption where the trees are unloaded and chipped.

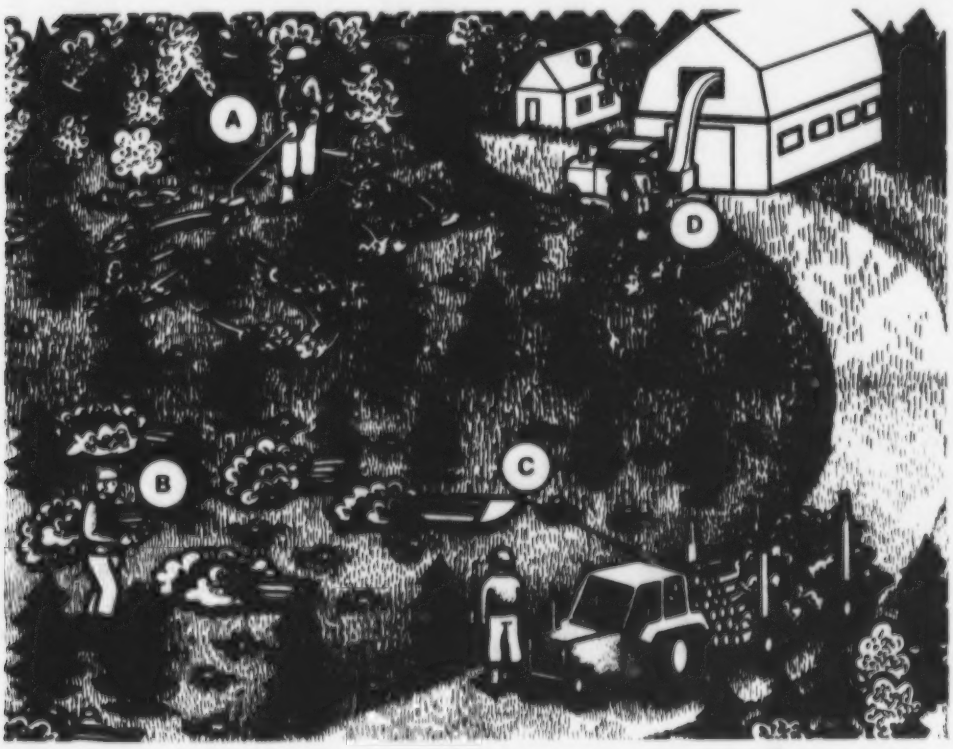


Figure 6.4
Manual Harvesting with Winch and Forwarder

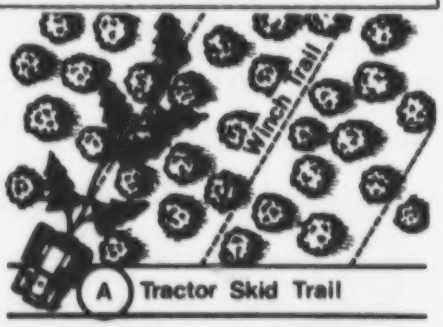
A. Pre-commercial thinning with a clearing saw and using directed felling.
B. Manual bunching in the stand with butts facing the tractor trail.
C. Winching of bunches to trail and loading of bunches on a light trailer using a wire crane loader and a skid pan. The cone shaped skid pan reduces friction and the chances for the load to get stuck. The load on the trailer is then transported to a road or a landing or the place of consumption.
D. Chipping at roadside or landing or place of consumption.

6.2 Harvesting System: Commercial Thinnings

The silvicultural goal of commercial thinning is to reduce the number of stems in the stand. This will improve the living conditions for the remaining trees. (Compare this to the spacing out of carrots in a garden - it speeds up the growth). The operation is called "commercial" because the trees harvested can be processed into products like pulpwood or small sawlogs. The logging residues such as tops and branches can be chipped. The trees are of medium size, i.e., 10 - 20 cm (4 - 8 inches) in stump diameter and 10 - 20 metres (33 - 66 feet) in height. Normal age is 25 - 45 years.

6.2.1 System 1: Whole Tree

This system requires a distance of 30 - 60 metres (100 - 200 feet) between tractor skid trails. The trees are felled away from the tractor trail, that is, with the butts towards the winch trail. The winch trails are laid out in a herring bone pattern at an angle of about 45° to the tractor trail. The tractor is positioned at the end of the winch trail. The main line wire is pulled out and the trees are attached to it using chokers. The trees are then winched to the tractor which skids then to a landing area. Here the branches are removed and small sawlogs and pulpwood are cut off. The branches and the tops are then chipped. The whole tree, complete with branches and tops, is taken out. This method is often called a "whole tree logging system".



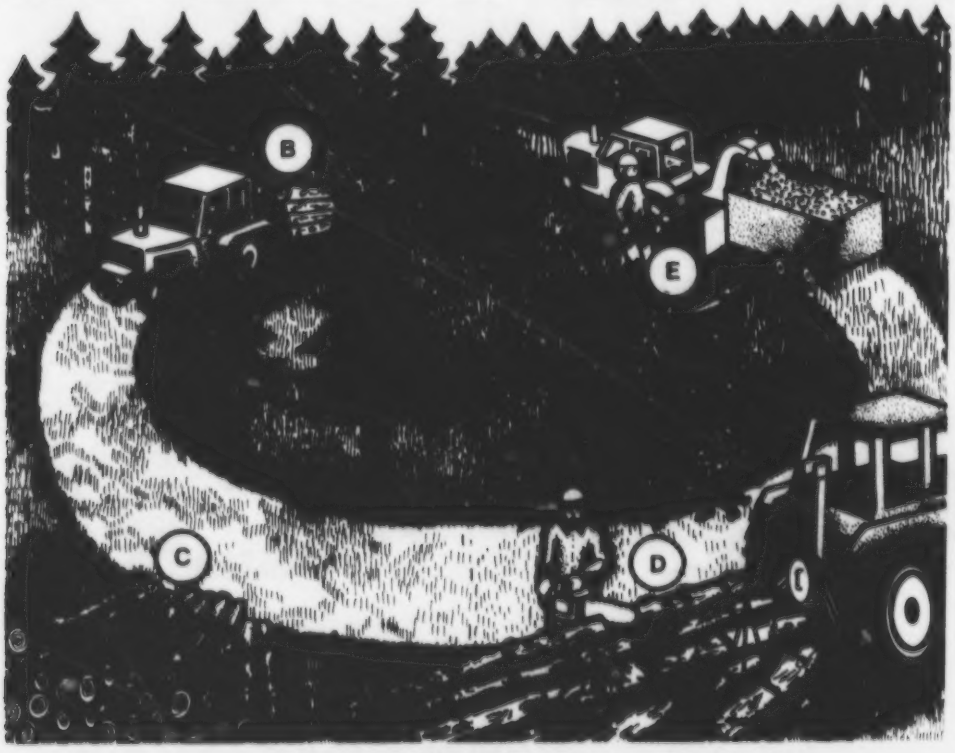


Figure 6.5
Whole Tree Harvesting

A. Directed felling with the individual tree aligned in a herring bone pattern along the winch trail. These trees are then attached to the winch line using chokers.
B. Trees are winched to the tractor.
C. The load of trees is transported (skidded) out to the landing.
D. Limbs and tops are removed and small sawlogs and pulpwood are cut off.
E. Tops and branches are chipped.

6.2.2 System 2: Shortwood/Winch

This system requires that the tractor trails be laid out 30 - 60 metres (100 - 200 feet) apart. The trees are felled towards the trail in a herring bone pattern. The limbs and tops are removed. The small sawlogs and pulp sticks are cut off and bunched along a winch trail.

The logs and pulpwood are winched out and loaded on a trailer using a wire crane loader. The tops and branches are carried out manually to the trailside and then chipped. The load of logs and pulpwood is taken out to a truck road.

This is called a shortwood logging system since logs and pulpwood are produced in the stand and winched out.

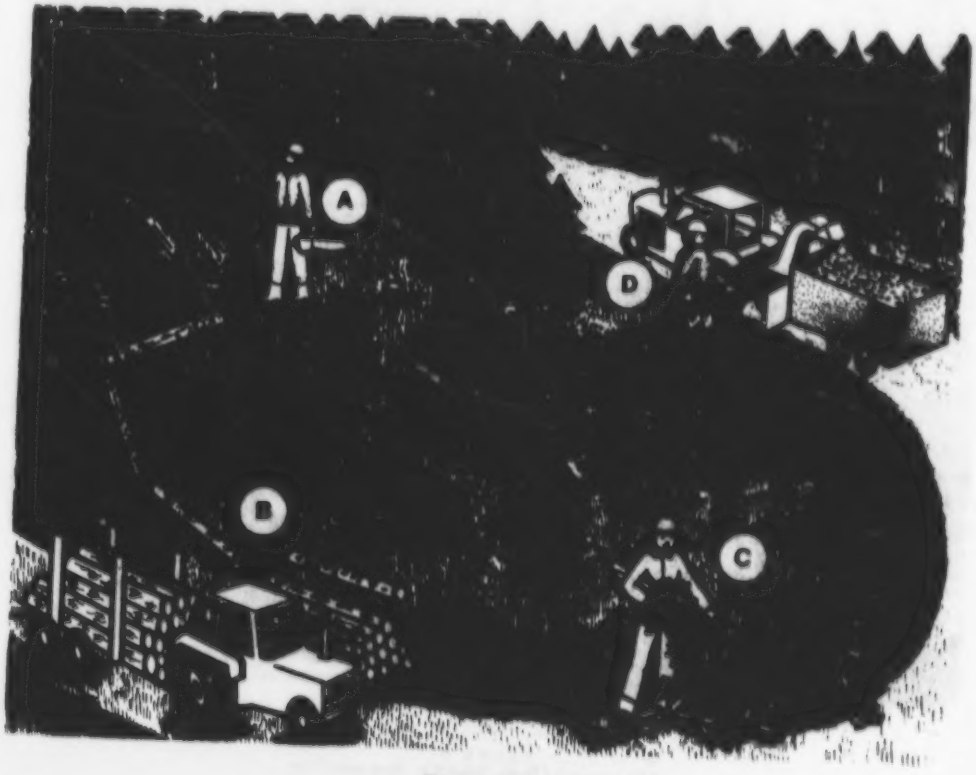


Figure 6.6
Shortwood Harvesting with a Winch

A. Trees are felled, branched and bucked and the products bunched along the winch trail.
B. The sawlogs and pulpwood are both winched out and loaded on the trailer using a wire crane loader.
C. Tops and branches are manually carried out to the tractor trail.
D. Tops and branches are chipped.

6.2.3 System 3: Shortwood/Tree-length

This system requires tractor trails to be laid out 30 - 60 metres (100 - 200 feet) apart. The trees are felled towards the trail in a herring bone pattern. The limbs are removed but the top is not cut off. The small sawlogs and pulp sticks are cut off except for the last piece which is left with the top. The material is then bunched.

The sawlogs, pulpwood and the pieces containing the tops are winched out and loaded on a trailer using a wire crane loader. The load is taken out to a landing where the tops are cut off with a chainsaw directly on the loaded trailer. The tops are then chipped.

This method is a mixture of a shortwood (logs and pulpwood) and a tree length/segment system (a section of the tree is taken out).

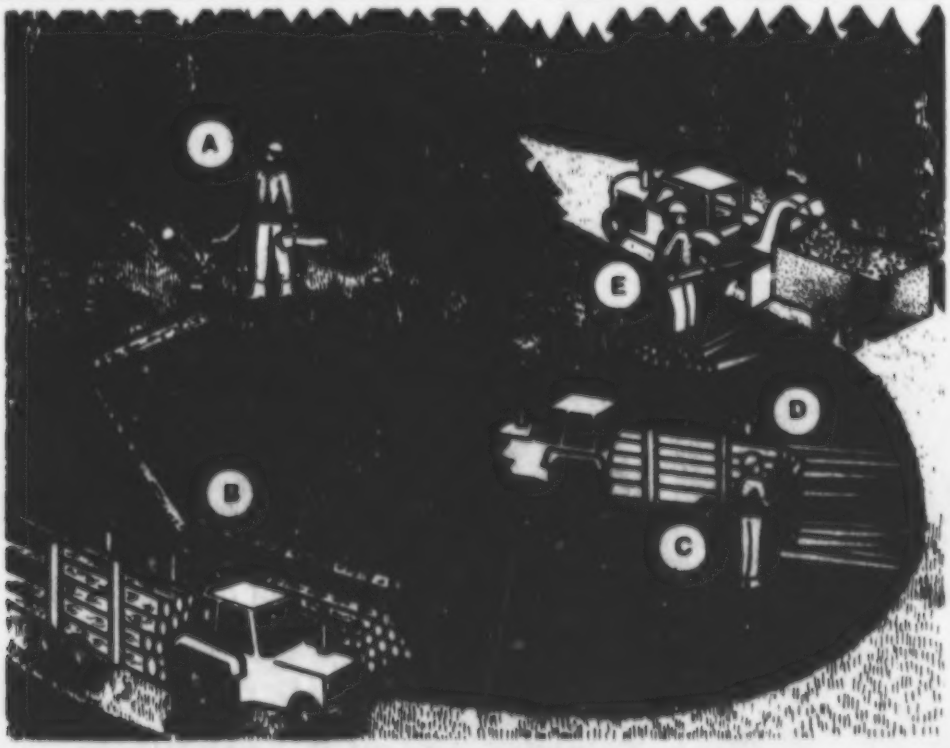


Figure 6.7
Shortwood/Tree Length Harvesting

A. Trees are felled, branched and bunched along the winch trail - the tops are not cut off.
B. The sawlogs, pulpwood and pulpwood with the tops attached are winched out and loaded on the trailer with a wire crane loader.
C. At the landing the tops are cut off and chipped.
D. Cutting off the tops.
E. Chipping of tops.

6.2.4 System 4: Full Tree

This system requires tractor trails to be laid out 30 - 60 metres (100 - 200 feet) apart. The trees are felled away from and perpendicular to the tractor trail. No limbing or bucking takes place. Trees are bunched along the winch trail where this is possible. The bunches are winched to the trailside and chipped.

This is a full tree logging system (the whole tree is extracted). It is only suitable for small dimension stands where it is not economical to take out small pulpwood. The limiting factor is the capacity of the chipper.

If the trees are large, they can be cut into irregular-length sections. This is called a "tree segment logging system".

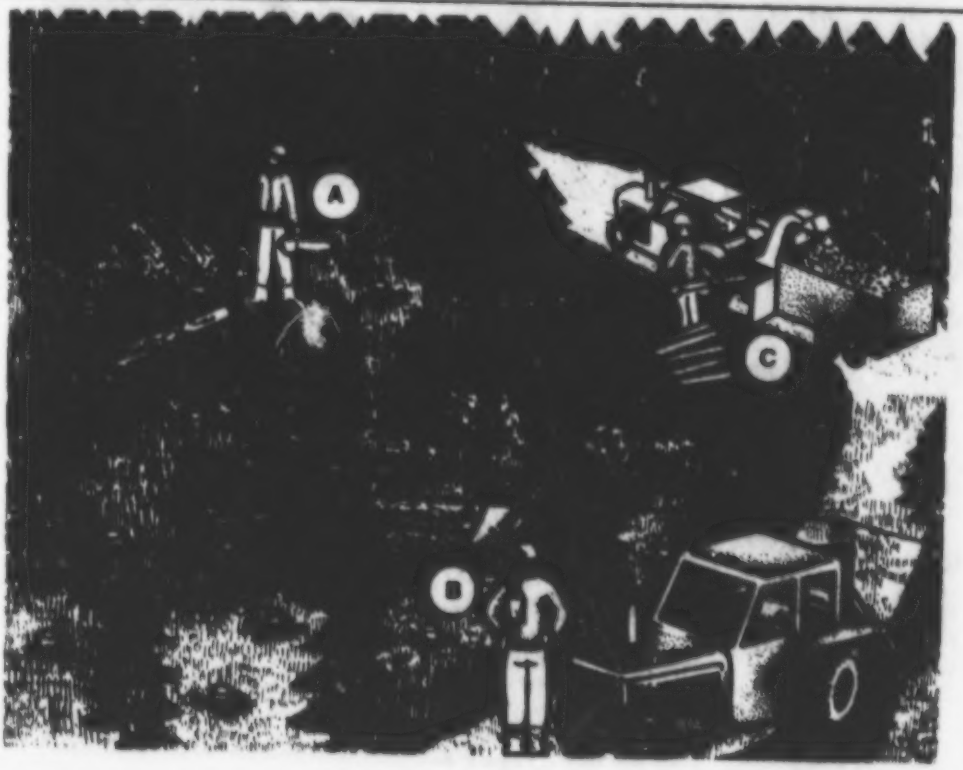


Figure 6.8
Full Tree Harvesting

A. Directed felling of trees away from the tractor trail and bunching where it is possible.
B. Winching out bunches to tractor trail.
C. Chipping of the whole tree or tree segment (pulpwood is not taken out).

6.2.5 System 5: Shortwood/Forwarder

This system requires tractor trails to be laid out 15 - 30 metres (50 - 100 feet) apart. The trees are felled towards the trail. Smaller sawlogs, pulpwood and tops are cut off and manually bunched along the tractor trail. A standard forwarder picks up the logs and pulp sticks and takes them to roadside or landing. The tops are then separately transported to the consumer and chipped.

This is a shortwood logging system because sawlogs, pulpwood, and tops are taken out. The off-road transport in this system is done with a big standard forwarder using a knuckle boom grapple loader.

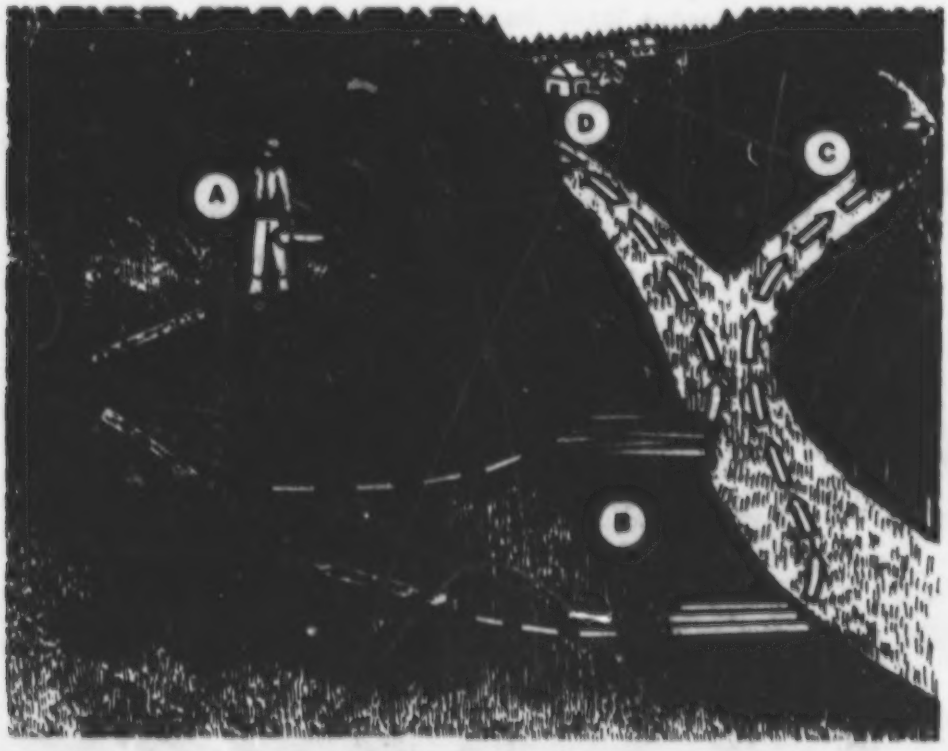


Figure 6.9
Shortwood Harvesting

A. Trees are felled, branched and bucked. The products are manually separated and bunched in a zone along the trail where the tractor operator can reach them.
B. Transportation of products to landing (sawlogs, pulpwood) and tops to landing, roadside or consumer for chipping.
C. Sawlog and pulpwood brought to landing.
D. Tops to be chipped or transported to chipper.

6.2.6 System 6: Tree Length

This system requires tractor trails to be laid out 30 - 60 metres (100 - 200 feet) apart. The trees are felled away from the trail. No limbs or tops are removed. The felled trees are winched to the tractor trail and pass through a "wrap around" limbing device attached to a stump. The limbed stems are then cut into sawlogs and pulpwood and the tops and branches are chipped.

The use of a limbing device in combination with a winch limbs the trees as well as piles the branches along the trail ready for chipping. The limbed stems can also be transported to a landing by a grapple skidder, clam bunk skidder or a forwarder and cut up on the landing.

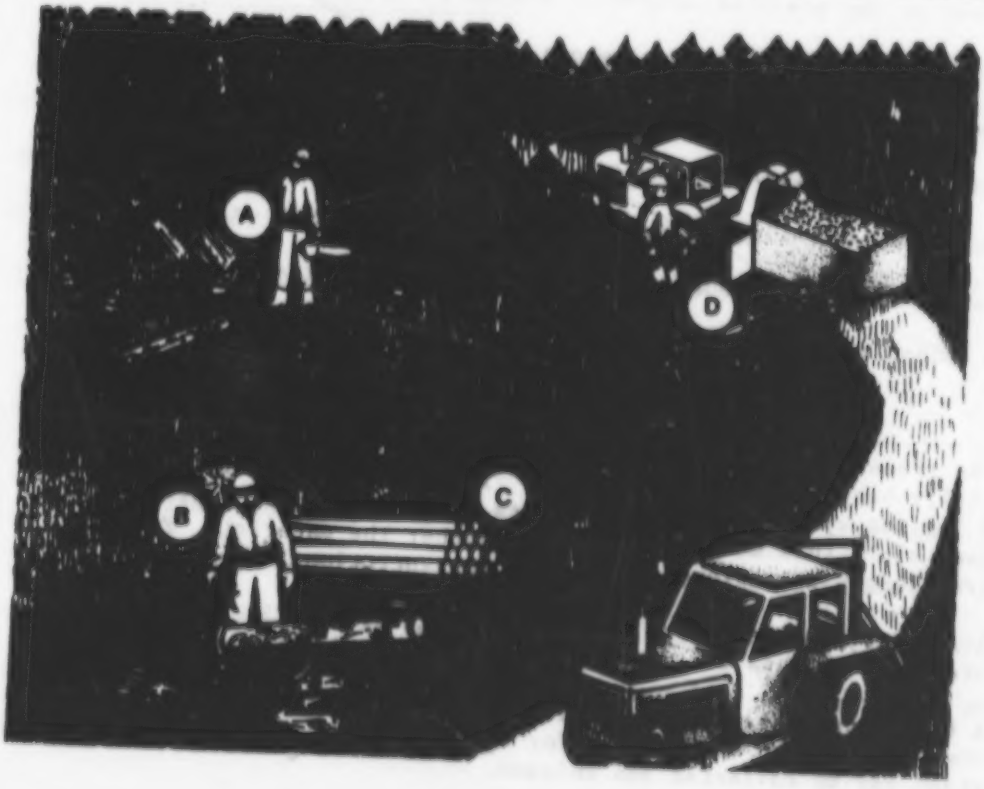


Figure 6.10
Tree Length Harvesting

A. Directed felling of trees away from the tractor trail.
B. Winching the tree to the trail through a limbing device fastened on a stump.
C. The limbed stems can be cut up on the spot or transported to a landing for processing.
D. Chipping of logging residues.

6.3 Harvesting Systems: Clear-Cut or Final Cuts

A final cut or a clear-cut is an operation where all trees are removed and processed into sawlogs, pulpwood or chips. The silvicultural purpose is to clear the area in preparation for a new stand. This new stand can start from small natural seedlings already in the ground (natural regeneration) or by preparing the site and planting seedlings (artificial regeneration).

The clear-cut can take place by using any of the methods described in the previous chapter. The full trees can be brought to the roadside and processed there (whole tree system). They can also be limbed and brought out in tree lengths for transporting or processing (tree length system) or they can be limbed and bucked in the stand and brought out as sawlogs, pulpwood, etc. (shortwood system).

Chipping of tops and residues may be justified depending upon the amount available.

The trees in a clear-cut operation are normally mature and substantially bigger than in a thinning. If fuel chips are to be produced, a logging system which concentrates the branches and tops should be used since this makes less work to gather the material. Full tree or tree length operations create this concentration.

A full tree system using skidding to a landing will concentrate branches and tops but might also clutter the landing area.

A tree length system with skidding to a landing will bring tops and some branches to the landing for chipping. Branches left in the stand can be collected and chipped.

A shortwood system can bring out logs, pulpwood and tops. Branches left in the stand can be collected and chipped.

6.4 Harvesting Systems: Clean-Up Operations

In cases where the trees that are to be felled and chipped are scattered along roads and fields, the operator has two options: (1) to fell them and move the chipper along the road, or (2) to fell and collect them and bring them to the chipper.

Whatever method chosen, the operator should fell the trees in such a pattern that further handling is made as simple as possible.

6.5 Farm Tractor Mounted Chipper

A farm tractor driven chipper requires PTO shaft power of 30 kW (40 hp) or greater. Several chippers of Scandinavian manufacture are on the market for about $10,000 each and a Canadian made machine will soon be offered at about $8,500. Such chippers can produce three tonnes of chips per hour, enough to supply more than a year's fuel for an average house in four hours of operation.

6.6 Drying

Dry fuel wood chips are stable in storage, do not freeze in bins, and burn best in most small furnaces. It is therefore advisable to dry the fuel. Drying can be accomplished in several ways, including drying or partially drying roundwood before chipping, or drying the wet chips after they have been produced.

6.6.1 General Requirements for Fuel Wood Drying

In general, wood drying occurs when temperature, air movement, and relative humidity are favourable. When there is much end grain

exposed, precipitation can quickly undo long drying times. Successful drying requires exposure of bare wood to the atmosphere. Favourable air drying temperatures are well above the freezing point, preferably 10°C and higher.

> No appreciable drying occurs when the wood is below freezing, so most of the winter in much of Canada is not a time for natural drying. In those areas of Canada where winter temperatures may be favourable for drying, the relative humidity is probably too high most of the time for appreciable drying.

6.6.2 Roundwood Drying

Felling trees with the leaves on, and letting them transpire moisture for a time (sour felling) can reduce the moisture content of the wood usefully. Using this method, hardwoods dry to about 40% moisture content in a few weeks. If they are cut into sections and piled after these few weeks, they should dry further. Sectioning and piling them when first cut accomplishes the same thing, but the wood would be slightly heavier to handle. If chipping of whole trees is to be done, allowing the trees to dry for a time with the leaves on means less chip drying is required to obtain a stable storage material.

In instances where an individual must supply his own chips, or where a supplier is just beginning his business and yard storage space is available but covered storage scarce, storing and drying wood in the round form and chipping in small batches may make good sense.

Drying roundwood in piles is most successful when a large bare wood surface area is exposed to drying air. Woods with impermeable bark, such as birch and cherry, dry very slowly when piled in long lengths. Warm, dry air must reach roundwood surfaces in order for drying to occur. For this reason, only the outside tiers of large, tight piles will dry usefully and pieces of roundwood near or on the ground will dry little. There are so many variables associated with natural roundwood drying that specific recommendations of procedures which will suit very many particular cases are not possible. A general understanding of the process of drying, as outlined here and in the section on moisture content, will help an individual to design for particular needs. General experience in most of Canada tells us that at least several warm, dry summer months are required to usefully dry chunk firewood. Roundwood in longer lengths will take longer than the short chunk fuelwood because the longer lengths have less exposed wood surface. A roundwood inventory for drying and eventual chipping can be planned on this basis, and refined with experience.

6.6.3 Chip Drying

The technology for quickly drying large amounts of wood particles using high temperature heat sources is well established. However, the capital investment required for such technology is beyond the capability of most users or suppliers of fuel chips. Even if the supplier were large enough, there is a serious question whether burning fuel in order to dry fuel can be economically justified. Sun-warmed air seems to be the most practical option for drying fuel wood chips.

A single chip of wood has a very large surface-to-volume ratio and therefore is easily dried. When piled together chips form a bulk through which moisture moves only very slowly. The spaces between piled chips are small, and therefore some force must be used to move air through them. With such air movement, each chip can begin to approach the condition of being a single, exposed chip. The limiting factor then becomes the condition of the air which is passing around the chip. Once the air has been saturated with moisture from chips, it has no additional drying effect as it continues through the pile. The quantity of air moving through a chip pile and its condition when it first enters the pile are the important factors in determining the

drying rate of a mass of chips. These variables and their effects on drying have been worked out for many types of grain, but so far there has been no systematic study, to our knowledge, for fuelwood chips. Work currently underway is addressing this, but in the meantime only a few tests form the basis for developing successful methods and hardware for other particular cases.

A "hotspot" drier designed for grain works well at cooling and reducing the moisture content of moist chips in local areas in a storage pile. Placing a perforated air passage in the base of a chip bin and using this to draw air through the chips has proven successful for drying a winter's supply of initially wet chips in a few summer months.

Recommendations as to chip bin design, fan size and drying times for various conditions should be available upon completion of work which is underway.

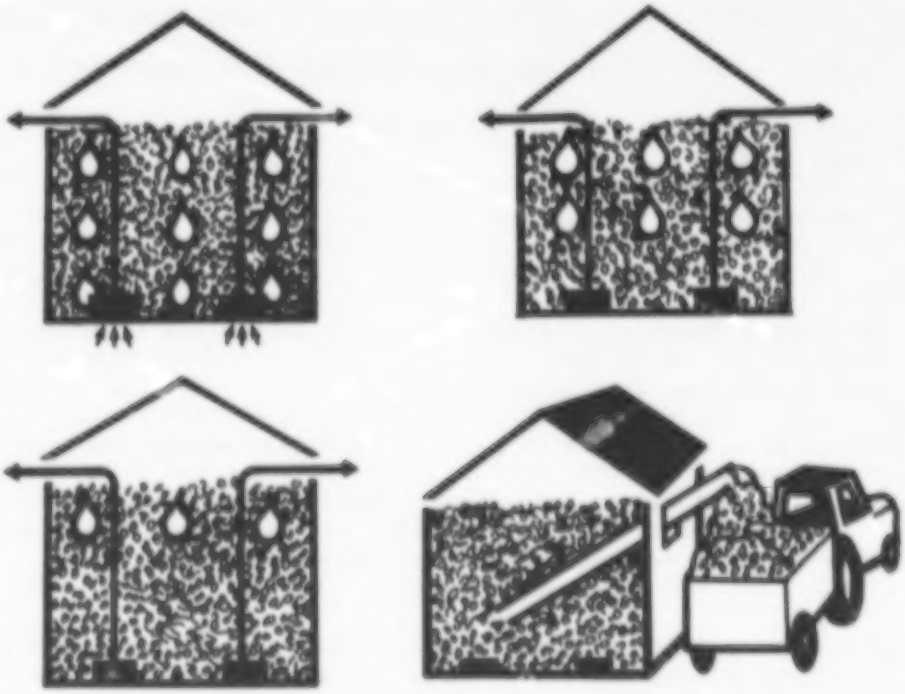


Figure 6.11
Drying Fuel Chips in a Bin

The chips do not all gradually become drier. Rather, they dry along a front which moves through the bin in the direction of air flow. There are, therefore, wet chips and dry chips in the bin during drying.

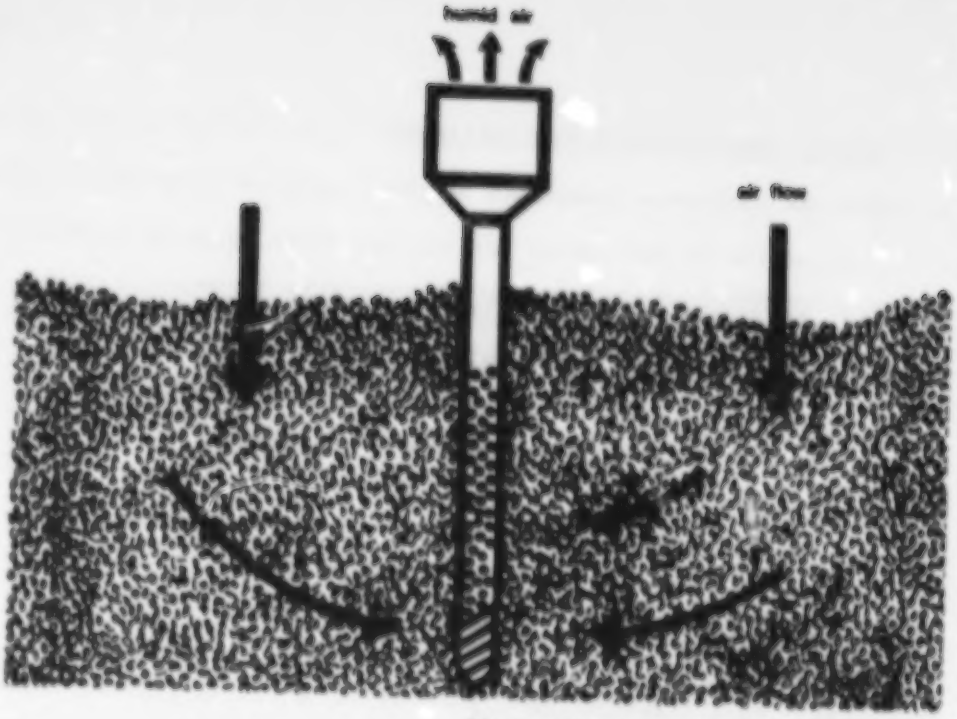


Figure 6.12
Grain Dryer Used for Chips

Grain aerator drying and cooling fuel wood chips. The drier, using a small fan, moves air through the chips into its lower perforated tube and out into the atmosphere.

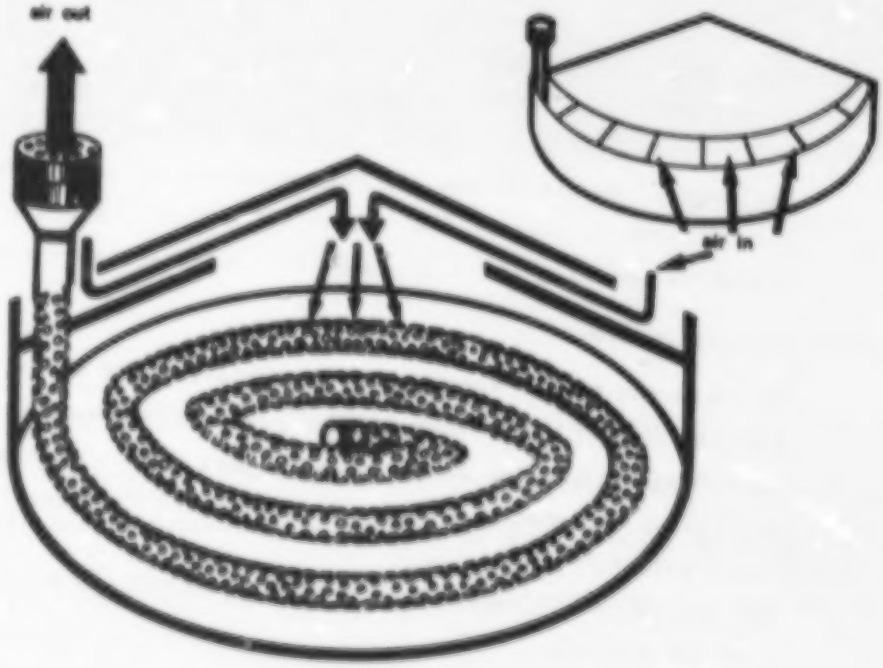


Figure 6.13
Ventilation Method for Drying Chips

Conical wood chip storage and drying bin. Perforated drain pipe on bin floor allows drying air to be forced through chips. The lower sectional view shows the pipe. The smaller view above shows the exterior of the bin. The cover does not fit to the edge, and the overlap allows air movement through the chips.

6.7 Supply Organizational Possibilities

When an individual landowner or small contractor considers going into the production of fuel chips for his own needs or to sell, there are a number of aspects to consider.

- Raw Material Supply. Is his own woodlot big enough? Can he purchase raw material in the area? Such things as transport distance and equipment should also be considered.

- Fuel Chip Production. Should the chips be produced in the forest (along a tractor trail), on a landing (roadside) or at "home" (in the yard) or at the distribution centre?

- Fuel Chip Storage. Should the fuel be stored primarily as roundwood in the forest along the trail, on the landing or at a storage area adjacent to the house or the distributor, or as chips?

- Fuel Chip Quality and Storage. Will green chips or dry chips be produced? Will there be screening and drying procedures?

- Equipment. Should he own all the equipment or use a contractor for part or most of the operation? Should he start a co-operative approach where a number of landowners work together?

Two basic principles are:

- Minimize the manual handling of raw material and chips. Production of fuel chips from logging residues and small trees is very labour intensive and it usually pays off to carefully scrutinize the whole operation from stump to consumer to eliminate wasteful procedures.
- Use available equipment for harvesting, chipping, transportation and storage.

The operator might very well be able to convert existing equipment or buildings rather than have to start from scratch. For instance,

he may have a farm tractor, a barn and suitable trailers. If he lacks any of these items it might be more economical to use a contractor or a cooperative approach.

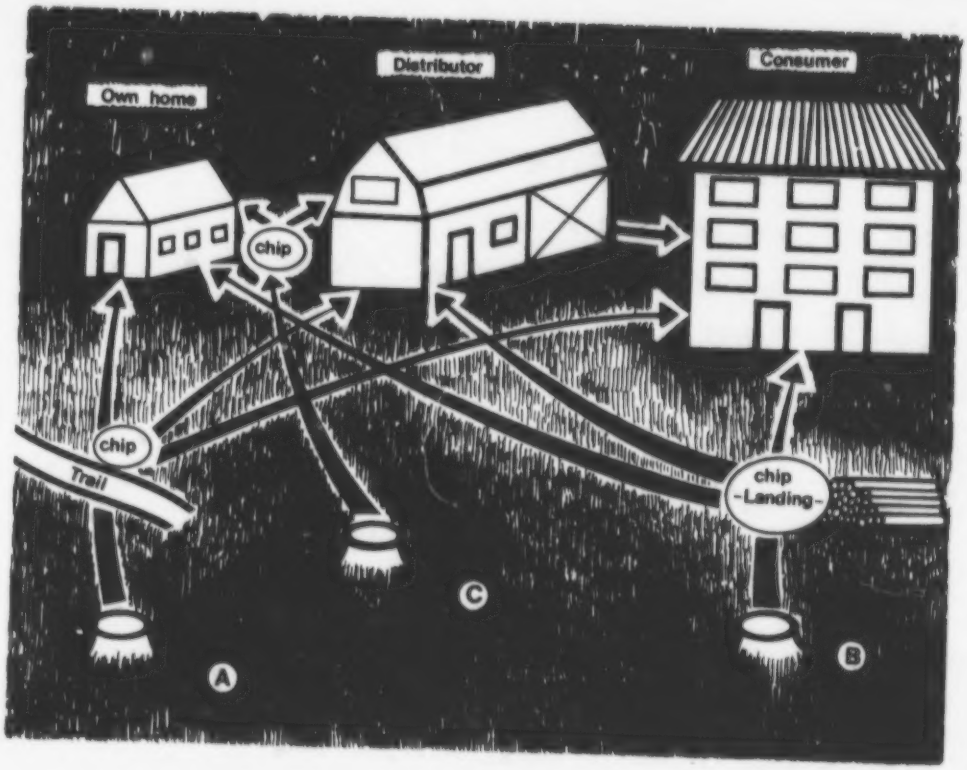


Figure 6.14

Harvesting and distribution options.

The landowner or the small contractor/distributor can produce his fuel chips (A) in the forest, (B) on a landing, (C) at home or at the distribution centre. A time lapse of 8 - 12 weeks between felling of the tree and chipping it improves the chipping results and reduces the moisture content.

7. EFFECTS OF CHIP QUALITY ON USEFULNESS AND STORABILITY

7.1 Moisture Content

7.2 Density and Species

7.3 Wood Chip Fuel Pricing

7.4 Chip Size and Distribution

7.4.1 Production Conditions and Size Distribution
- (a) Chipper Type
- (b) Chipper Speed and Power
- (c) Knife Condition
- (d) Wood Size
- (e) Wood Moisture Content
- (f) Wood Density and Decay

7.4.2 Consequences of Varying Chip Sizes

7.5 Foreign Matter

7.5.1 Gravel and Dirt

7.5.2 Fungal Spores

7.5.3 Larger Foreign Objects

7. EFFECTS OF CHIP QUALITY ON USEFULNESS AND STORABILITY

Fuel chip quality is determined by size and size distribution, moisture content, foreign matter content, species, biological degradation and fraction of bark and foliage. The quality of fuel chosen depends upon the characteristics of the burner used.

7.1 Moisture Content (MC)

Living trees vary in moisture content with species and size. Smaller trees, because of larger proportions of sapwood, tend to be wetter. On the average, pulpwood or sawlog sized trees can be expected to have moisture contents of about 70% if hardwoods (deciduous trees) and 90% if softwoods (conifers).

> Dry basis moisture contents are determined by first weighing a sample of wet wood. It is then dried in an oven to constant weight at 104°C. Subtracting the dry from the wet weight gives the weight of water removed. Dividing the water weight by the dry wood weight gives a ratio. Multiplying this ratio by 100 gives percentage moisture content, dry basis. Moisture contents of solid wood can also be measured, within the limits of 7% and 21%, using an electrical resistance meter and correction factors for species and temperature.

From the moisture condition of the living tree down to about 30% MC there is liquid water in the wood which is available for fungi to decay the wood. This water can freeze wood particles together in cold weather. Below 30% MC, all water in wood is bound in wood substance and therefore unavailable for freezing or for growth of microorganisms. This suggests that for anything other than short-term storage, chips or solid wood should be dried to some moisture content below 30%. Wet sol-

id wood will eventually decay. Wet chips will decay fairly quickly, heat up due to fungal growth and may produce large amounts of fungal spores. In addition, wet chips can freeze into unmanageable masses in winter.

Wood which reaches equilibrium with outdoor air will have a moisture content somewhere between 12% and 20% in most of Canada for most of the year. This can vary somewhat depending upon local storage conditions. Near the ground or in a moist location the wood not in contact with the ground may approach 30% MC. In the attic of a sun-heated storage building it may get to less than 12%. Wood chips having moisture contents of 30% or less are ideal for use in stokers which burn their fuel directly inside the combustion chamber of a furnace, although combustion chambers can be modified with firebrick so they will work with fuel up to 100% MC. Stokers which feed an external combustion chamber linked to a furnace are designed to operate continuously on 100% MC or wetter chips. Preheaters require chips wetter than 30% MC in order to burn reliably.

Dried wood fuel contains more potential energy per unit of volume than wet fuel. Furnaces using dry fuel have greater output capacity than would the same furnace burning wet chips. Stokers designed primarily for wet chips are more costly than those designed primarily for drier fuel. These disadvantages of wet chip stokers, plus the problems with storage and cold-weather handling of wet chips, would seem to make them an impractical fuel for most installations. The only cases where wet chip systems would seem attractive are where fuel can be produced easily from wet wood on an as-needed basis.

7.2 Density and Species

Fuel chips vary in bulk density with wood species, moisture content, packing, and amount of decay.

> Species differences can be illustrated by comparing a softwood and a hardwood mixture. Eastern spruce (Picea sp.), balsam fir (Abies balsamea), and pine (Pinus resinosa and strobus) mixed chips have an average bulk density of approximately 180 kg per cu m (11 lbs per cu ft) well-packed and at 20% moisture content. Maple (Acer rubrum and saccharum), birch (Betula lutea and papyrifera) and poplar (Populus tremuloides and grandidentata) mixed chips have a bulk density of 220 kg per cu m (14 lbs per cu ft) at the same conditions. These are 12 mm (½ inch) fuelwood chips. The way chips are transported and handled can vary their packing, so it is important to be consistent when measurements are being made.

The denser species of wood have the advantage that they have a greater potential energy content per unit of volume, and therefore require slightly less storage space for a given energy content. Decay lowers wood density and reduces the heat value per unit of volume. A stoker hopper should be chosen that has sufficient low-density fuel capacity to run the system for at least 24 hours in cold winter weather. Because of design limitations, preheaters can normally hold enough fuel for only about 12 hours of operation under similar conditions.

Stokers and preheaters respond to heat load required by the heated space, not the energy per unit volume of fuel. With less dense fuel they simply run a little longer in order to heat the space. However, with very low density chips some adjustment of operation may be required. As long as the burner is not at the limit of its capacity to supply heat, there should be no effect on its ability to heat the space when low-density fuels are used. This means that dense, high quality hardwoods are not essential for practical heating with wood chips.

7.3 Wood Chip Fuel Pricing

To date in North America, there have been some fuel chipping trials using small-scale equipment, but not enough to develop a model which will allow prediction of profitability of a particular chip fuel business. Work currently underway is attempting to fill the gaps in the information and to construct the model.

> Billing customers for wood fuel chips should be done on a potential combustion energy basis as it is for the fossil fuels. This can only be accomplished with a reasonable degree of uniformity and accuracy by weighing delivered chips and determining their moisture content. Such things as species, degree of decay, and packing all affect chip bulk density greatly and therefore volume measurement alone can only be a rough guide. For small amounts of chips, and before automatic weighing equipment is available, representative volumes of chips from a batch can be weighed, and the total volume used to estimate a total weight. A small box of known volume and an accurate scale is all that is required.

7.4 Chip Size and Size Distribution

Fuel chips normally produced for domestic-sized stokers and pre-heaters are smaller than pulp chips. Fuel chips average 12 mm by 12 mm by 3 mm (1/2 inch by 1/2 inch by 1/8 inch). This small size gives good flow in small bins and small augers. It also gives effective surface-to-volume ratio for combustion in small chambers. This size chip produces small, light, ash particles which are easily blown from the combustion zone by primary air.

The size distribution of the chips depends upon chipper design, chipper knife sharpness, engine power, diameter of the roundwood being chipped, wood moisture content, wood density, and amount of decay in the wood.

7.4.1 Production Conditions and Size Distribution

(a) Chipper Type

Well-maintained and properly operated farm tractor mounted chippers commonly used to produce fuel chips are capable of producing usefully uniform chips. Disc chippers are most frequently used because they are a simple, easily-serviced design. Some of these chippers are equipped with powered infeed rolls which assist feeding and which help hold the wood rigidly as it is being chipped. This helps make uniform chips, especially from small-diameter material. Chippers incorporating a chip breaker into their design tend to produce more uniform chips than those without. The breaker splits and fragments the larger chips produced by the knives.

(b) Chipper Speed and Power

Chippers are designed to operate at a particular rotational speed, usually 540 rpm for tractor-mounted chippers. Operating at speeds below the design speed, such as when the machine is being overloaded, increases the fraction of oversize chips produced. This is because chip splitting during cutting, and when passing through the breaker, is reduced. An adequately powered chipper will therefore produce more uniform chips than one that is underpowered.

(c) Knife Condition

Sharp chipper knives produce better chips using less energy than dull knives. Dull knives produce large chips and slivers by splitting rather than cutting, particularly at the end of a stick being chipped or with small-diameter pieces such as twigs. The pulverizing action of dull knives produces more small particles and dust, especially with very dry, low-density or decayed wood.

(d) Wood Size

Very small material for chipping does tend, especially with dull knives, to turn sideways and slip through the knife opening without being cut into short chips. Pieces of twigs up to about 10 cm (4 inches) long appear in the chips under such circumstances. Large diameter twig pieces can cause jamming in augers when the twig diameter is about the same as the clearance between auger flight and tube. They can also impede chip flow in hoppers and into auger openings. The quantity of these larger particles that can be tolerated before equipment malfunction is dependent upon equipment design and operating conditions.

The slow-speed (1 to 10 rpm), large-clearance (about 2 cm or 3/4 inch), high-torque augers of most stokers have little difficulty with large particles. By comparison, a 10 cm (4 inch) grain auger with nearly the same clearance but turning at 580 rpm jams regularly because of such particles. The grain auger uses a motor of similar power to those on stokers, but since it runs at higher speed, it has less torque. There does seem to be a critical relationship between particle size and auger clearance, also. The grain auger clearance, even though only very slightly less than those in stokers, may be below the critical level.

(e) Wood Moisture Content

Moist wood cuts more cleanly and with smaller energy requirement than dry wood. Above approximately 30% moisture content, wood cutting characteristics do not change. Below 30% MC, wood becomes progressively more difficult to cut and more prone to fragmentation. Wood chipped when dry will have more fine particles in it as a result. Moist wood is more elastic than dry wood. Small, wet twigs and branches have a greater tendency than dry ones of winding up on chipper axles instead of

feeding into the knives. Some drying, such as in sour-felling, can therefore be advantageous when there are large amounts of small-diameter material to be chipped.

(f) Wood Density and Decay

Higher-density wood tends to resist cutting forces without damage better than softer woods. Wood that has been attacked by decay fungi loses strength dramatically even with a small loss of wood substance due to fungal digestion. Decayed or low-density woods tend to fragment more during cutting than the stronger, higher-density ones. Low density or decayed woods yield a greater fraction of fine particles than do the denser, stronger ones. Other factors being equal, the cutting forces required for the weaker woods are less, but the mass of wood produced per unit of time is also less.

7.4.2 Consequences of Varying Chip Sizes

Chips near the average size flow well in hoppers and bins, transport easily through properly designed screw augers, and burn well in small combustion chambers. Larger particles tend to block flow and sometimes jam augers. Very small particles (wood dust) are dirty and can cause respiratory problems for persons exposed to them. For these reasons, the amount of chipped material produced in the larger and smaller particle sizes should be as limited as possible. Conditions favorable for producing average-sized chips should be maintained.

Proper stoker and conveyor design, especially adequate auger clearances, permits use of greater amounts of large particles in the chip feed without problems. Larger particles tend to recirculate in the chip mass in hoppers rather than enter the outfeed. They can thus become an ever-increasing fraction of the material in the hopper unless the hopper is allowed to empty periodically. Not allowing complete emptying from time to time can result in bin outlet blockage by larger particles if many are regularly present in the fuel.

Chips could be screened to remove the larger particles. Dust could also be removed. With proper attention to design and operation of both chipper and chip transport equipment (including stoker augers), screening seems not to be essential. In commercial production, however, the increase in fuel reliability and uniformity resulting from screening might justify its small cost.

The amount of dust produced from chipping decayed or very dry wood can be considerable. The health effects of dust can be eliminated by wearing a dust mask when handling chips. The dirt aspects can be minimized by isolating the chip fuel area from the rest of the building. Fine, combustible dust in the air may be explosive under some conditions. This should be considered in any enclosed area where dusty chips will be agitated. There apparently have been no explosions, so far, resulting from chip dust. Nonetheless, the possibility should be considered when designing facilities where dusty chips will be handled.

Fluffy and self-adhering particles like sawdust and long, stringy particles like planer shavings and lathe coils do feed through stoker augers. But some, especially the longer ones, tend to bridge in bins and fire-break boxes unless they are mixed with a fraction of fuel chips. When it is anticipated that equipment will be used for some of these other fuel particles, a design with an agitating shaft in the fuel storage space should be considered. Such a mechanism will allow greater flexibility in fuel choice.

7.5 Foreign Matter

There is a wide variety of foreign matter which can appear in wood fuel chips. Gravel and dirt can be on the surfaces of wood as it is chipped. Soil can be picked up with chips if they are reclaimed from piles on the ground. Fungal spores can be generated in the chips if they are stored wet. Various foreign objects such as rocks, wires and nails can appear in chip fuel at times. All of this foreign matter can

cause problems. Handling and storage methods should be designed to minimise the amount of foreign matter.

7.5.1 Gravel and Dirt

Gravel and dirt acts as an abrasive which dulls chipper knives and scours auger flights and tubes. Abrasive wear on chipper knives requires them to be sharpened. Low-speed, high-torque augers used in stokers wear and weaken rapidly in areas where fuel compression is high unless their flights are thick and hard. Abrasive particles in the fuel are largely responsible for this wear.

Gravel and soil make up a large part of the noncombustible material that accumulates in the combustion chamber of a wood fuelled appliance.

In the case of a chip-fired stoker, this material is heavier than ash, and therefore tends to accumulate in the bottom of the combustion zone. This tends to clog grates and decrease primary air flow. The light ash is largely blown out of the combustion region by the air flow, and thus presents much less of a clogging problem. Frequency of grate cleaning is directly related to the amount of soil and gravel in the chip fuel. The presence of some of this foreign material in the chips is probably inevitable, and thus grate design should take this into account, allowing for easy manual or automatic cleaning.

7.5.2 Fungal Spores

Moist, warm wood chips, without air flow through them, are excellent media for fungal growth. Bark and foliage included with the chips makes them an even better fungal growth medium. Ordinarily, the first fungi to grow are the wood decay and mold fungi which grow best at room temperature. The heat of respiration of these fungi cause the

temperature of the chips, which are good thermal insulators, to rise. At higher temperatures, another type of fungi (especially aspergilli), grow favourably, and these tend to take over from the earlier colonisers. It is possible for the growth of these warm-temperature-loving fungi to elevate the temperature of the chips to the ignition point. Even if this does not occur, the fungi produce large amounts of spores which can cause allergies or fungal diseases (e.g. aspergillosis) in those who come in contact with them for extended periods.

> The best strategy seems to be to prevent fungal growth in the first place, but if it does occur it is important to prevent exposure of people to the spores. The spores are very small, about 4 micrometers (2 ten-thousandths of an inch) and very light, so they fly about easily and require a good dust mask to filter them out. Wearing an efficient dust mask, and overclothes (including ear coverings) that can be removed before going indoors protects the handler from contaminating himself and those he lives and works with. Loading hoppers directly from outside by sealed chute or tube allows contaminated chips to be used without infecting building interiors.

7.5.3 Larger Foreign Objects

A great many different foreign objects can find their way into the fuel chips. As long as they will pass through the feed augers, they will make their way into the ash and pose no particular problem. Rocks, concrete, wire, nails, springs, glass and a 15 cm (6 inch) spike are things that have been found in firebowl ash of small stokers. Larger objects will jam the augers and must be removed. This can be troublesome and dirty with a full chip bin, so it is to be avoided. Careful chip quality control is helpful in avoiding the larger foreign objects. This may be sufficient reason for screening if large chips alone are

not. With proper equipment design, particularly adequate auger flight-to-tube clearance, the allowable size for a foreign object (or large chip) that will still pass through the augers can be large enough so that fine screening is unnecessary.

8. COST ASPECTS

8.1 Equipment Costs

8.2 Installation Costs

8.3 Service

8.4 Fuel Costs

8.5 Bin Costs

8. COST ASPECTS

Cost factors differ from installation to installation and depend upon such things as:

- choice of equipment (stoker, preheater)
- price of equipment
- type of distribution system (air, water)
- back-up system used (existing, new)
- condition of chimney
- ease of access for installation

8.1 Equipment Costs

Typically, wood chip burning hot water boilers and hot air furnaces would cost about the same as similarly-sized solid wood burning units. In 1981 Canadian dollars, hot air furnaces would cost about $1,000 and hot water boilers would range from $1,500 to $2,000. Stokers for either system are identical and would cost between $1,500 and $2,500 while preheaters cost about $2,000.

8.2 Installation Costs

Both time and materials are involved. A retrofit installation may take one to two days to complete. It will require various materials such as sheet metal or plumbing and wiring supplies. The total cost will be about $1,000. A chip heating system in a new building would cost the same as a fossil-fuelled system except for the cost of a stoker or preheater and a chip storage bin.

The price for installation and the quality of work and materials can vary widely among contractors.

8.3 Maintenance and Service

Servicing for semi-annual cleaning, inspection and adjustment is no more involved than for a conventional oil fired system and should have similar cost. Current (1981) charges for such routine service in Fredericton, N.B., are about $30.00 per hour. Two two-hour visits are the most that should be required annually. Breakdown repair costs cannot be predicted. However, wood chip systems are simple and, in many cases, the owner or operator can diagnose and repair the fault without calling in a repairman.

8.4 Fuel Costs

Seasoned, split, hardwood firewood can cost less than equivalent amounts of other space heating fuels. Where wood is locally available chip fuel should have similar cost advantages in similar situations.

One cord of dense hardwood fuelwood contains about 80 cu ft of solid wood in 128 cu ft of space and weighs about 1.6 tonnes at 20% MC. If fuel chips are sold at a price equivalent to chunk firewood, the firewood price per cord should be divided by 1.6 to get the chip price per 20% MC tonne.

The Prince Edward Island chip heating project estimates the 1981 production cost of 1 tonne of 20% MC fuelwood chips to be $46. This is based upon experience producing chips for 30 homes for the 1980-81 heating season.

One home in Fredericton heated with wood chips and using a hot air furnace displaced 442 l of oil by 1 tonne of 20% MC wood chips as an average over the 1980-81 heating season. The displacement for the home using a hot water system, which also provides domestic hot water, was 416 l per 20% MC tonne. House details are given in Appendix IV.

8.5 Bin Costs

Storage for at least a few week's supply of chips is required at the site of the heating plant. The cost for providing such covered storage should be included in any analyses. Such costs can vary greatly with size and type. As examples, some exisitng buildings may be useable as chip bins, adding no cost to the installation. A partition might suffice to provide storage space. A plywood bin or metal silo might be more suitable in other instances. The cost for storage bins could therefore range from virtually nothing to a few thousand dollars for a metal bin to hold a year's supply of chips.

9.0 SUMMARY

Space heating using wood chip fuel is an attractive alternative where there is suitable wood available. Chips can be burned more cleanly and conveniently than solid wood. They can be manufactured from forest residues and otherwise unuseable trees and woody plants. The Scandinavian countries already have forest residue harvesting and wood chip burning infrastructure in place. It can be used as an example.

It is possible to retrofit most buildings with wood chip heating systems. Some can be done more cheaply and easily than others. Some existing heating plants can have stokers fitted to them without modifications to the building. It is important to follow approved procedures when making such conversions. Chip-fired heating systems in new buildings require careful design in order to make them most useful and convenient.

Wood chips are more bulky than the fossil fuels. The equipment required to automatically feed wood chips into a furnace is somewhat larger than that required for liquid or gaseous fuels. Nonetheless, most homes or buildings can accept a chip-fired system along with a few week's supply of fuel.

There are safety standards for stokers and their installation in Canada. They are prepared by the Canadian Standards Association. The installation portions are written into the National Building Code.

There are several types of equipment designed to burn wood chips. A number of systems have been developed but not all are readily available in North America. Those currently developed include underfed and overfed, direct-fired stokers, stokers firing an external combustion

chamber, and gravity-fed preheaters. Each has its own operating, maintenance and convenience characteristics. Each type can be tested for efficiency using the same instruments as those normally used by oil furnace servicemen. A troubleshooting chart can assist operators and servicemen with diagnosis and repair procedures. Stokers are simple enough that mechanically-inclined operators can carry out most maintenance and repair.

Several forest thinning and harvesting systems using farm tractors and attachments are suitable for production of wood chip fuel. Other products such as pulpwood and sawlogs can be produced at the same time. The system should be chosen on the basis of the raw material available and the treatment desired for the forest stand.

Fuel chips are stable in warm-weather storage only if they are dry. Wet chips are difficult to handle in freezing weather. Dry chips are easier to burn efficiently but in some circumstances high moisture content is acceptable. Drying chips is simple and requires energy only to move air through the chips. Roundwood drying seems simple also, but there are many factors which make it difficult. Roundwood is particuarly slow-drying in long lengths. Felling trees with leaves on, and leaving them for a few weeks before chipping, can speed the chip drying process and make twigs easier to chip.

The degree of reliability of wood chip heating systems is partially dependent upon the size of the chips and the amount of foreign matter they contain. Dust and fungal spores in chip fuel can cause health problems. All of these would require quality control by a commercial producer. Assessment and control procedures are available for this.

In 1981 Canadian dollars, a hot air furnace would cost about $1,000. A hot water boiler would cost about $2,000. To burn chips in these units would require a stoker costing between $1,500 and $2,000 or a preheater could fire the same heating plant for $1,000. The preheater has several disadvantages to offset the lower cost. Retrofit installations in buildings already containing a hot air or hot water heating system cost approximately $1,000 for labor and materials. In new buildings, a chip heating system is basically the same as a fossil-fuelled system except for the additional cost of a stoker or preheater and a chip storage bin. Chip fuel would probably cost about the same as chunk fuelwood.

Chippers to fit on a farm tractor, capable of producing up to 3 tonnes of chips per hour, cost between $8,500 and $10,000.

APPENDICES

I	GLOSSARY OF TECHNICAL TERMS
II	CONVERSION FACTORS
III	EFFICIENCY CURVES
IV	CASE STUDIES
V	GUIDE FOR FURTHER READING
VI	PERSONAL INDEX

APPENDIX I

GLOSSARY

Auger - a device for conveying materials by the action of a screw-like mechanism, fitted inside a suitable pipe, and which is then rotated relative to the pipe by a motor.

Barometric Damper - a swinging circular plate-like device usually set in the smoke pipe between the furnace and the chimney. It maintains a constant draft at the furnace outlet.

Btu - a British thermal unit. A unit of energy equal to the amount needed to raise the temperature of 1 lb of water by 1 Fahrenheit degree.

Capacity Factor - The number of hours a burner runs in a 24 hour day divided by 24. May be expressed as a percentage. For example, a stoker which runs for 12 hours on a particular day has a capacity factor of 12 ÷ 24 = 0.5 or 50%.

Cleaning Saw - a long-handled portable power saw used to fell small trees and brush by cutting them near ground level while the operator stands rather than having to bend or kneel.

Cord - a common measure of firewood and pulpwood equal to the volume of wood in round (not split or chipped) form that can be neatly stacked, with the individual pieces parallel to one another, in a pile 4 feet wide, 4 feet high and 8 feet long. The pile volume is 128 cubic feet, but due to air spaces between the pieces, the actual solid wood volume is about 85 cubic feet.

Creosote - chimney deposits formed from condensing gases in wood smoke. Creosote is often initially liquid, but dries to a highly flammable flaky or solid form.

Damper - a sliding, swinging or rotating plate which acts as a valve to control the flow of air into, and smoke out of, wood burning equipment.

Degree Days - a measure of the severity of the heating season in a particular geographic location and based on a temperature of 18°C. The degree days for any one day are calculated by finding the dif-

ference between the mean temperature for that day and 18°C. The annual total degree days are the sum of the daily figures. Degree days for various locations are calculated and tabulated by the Atmospheric Environment Services of Environment Canada.

Density - the mass (weight) of a material in a given volume, i.e. kilograms per cubic meter, pounds per cubic foot.

Directional Felling - dropping trees in preferential directions for ease of pickup.

Draft - the difference in air pressure inside and outside a furnace or chimney. Can also mean the flow of air.

Draft Regulator - same as Barometric Damper (see above).

Efficiency or Appliance Efficiency - the percentage or fraction of the chemical energy in the fuel actually converted to useful heat by the furnace or boiler.

Excess Air - air admitted to a burner over and above the amount theoretically needed for complete combustion.

Flight - the helical, flanged, screw-thread like part of an auger. The flight is attached to a shaft and, when placed in a pipe and made to turn by rotating the shaft, is able to convey various types of material along the pipe.

Fungi - a group of plants including mildews and molds that have no leaves, flowers or green colour and reproduce by means of spores.

Forwarder - a rugged, four-wheel drive, forestry machine able to travel off road and used to transport trees from the felling area to roadside by carrying them clear of the ground.

Green Wood or Chips - undried, freshly cut wood or chips from a live tree.

Higher Heating Value - the energy obtainable from a given quantity of fuel upon complete combustion and cooled to the original fuel temperature with any water vapour formed condensing to a liquid.

Kilowatt Hours (kWh) - a unit for measuring energy in electrical terms, and the standard unit for energy in the SI metric system.

Landing - a cleared area in the forest accessible to highway trucks to which trees are brought by heavy off-road forestry machines. The trees may then be further processed and/or loaded onto trucks for transport to other locations.

Megajoule - The SI unit of energy is the joule. A megajoule is one million joules and is equivalent to slightly more than a quarter of a kWh of energy.

Moisture Content (MC) - the fraction or percentage of water in wood and calculated on either a dry or a wet basis.

$$MC(dry) = \frac{\text{weight of water removed in oven drying}}{\text{oven dry weight of wood}} \times 100$$

or

$$MC(wet) = \frac{\text{weight of water removed in oven drying}}{\text{original weight of wood including its moisture}} \times 100$$

Ovendry Wood - wood dried to constant weight at about 105°C and low humidity. By definition, wood with zero moisture content.

Pneumatic Conveyor - a device for transporting solid materials by carrying them along in a stream of air through a suitable piping system.

Pulp Stick - a piece of wood 4 ft. or 8 ft. long to be used to produce woodpulp. Also called pulpwood.

rpm - revolutions per minute.

Seasoned Wood - wood which has lost a significant amount of its original (green) moisture. There is no universally accepted definition of the moisture content of such wood.

Skidder - a rugged, articulated, four wheel drive off-road forestry tractor equipped to permit it to drag, or skid, trees from the felling area to roadside or to a landing.

Skid Pan - rounded piece of sheet metal upon which ends of material to be slid along the ground is place to ease its passage.

Sour Felling - felling trees complete with foliage and permitting them to lie on the ground for some time in order that moisture in the wood be drawn off and evaporated through the foliage.

Thinning, pre-commercial - removal of small trees with no conventional commercial value to improve growth of remaining trees.

Thinning, commercial - removal of trees large enough to be sold as pulpwood to improve growth of remaining stand.

Ton - a unit of mass (weight) equal to 2,000 pounds used in the Imperial system of units. Also called the Short Ton.

Tonne - a unit of mass (weight) equal to 1,000 kilograms (or 2,200 pounds) in the SI metric system.

Tree Length - tree complete with branches removed from forest in one piece.

Tree Segment - piece of tree trunk which may be further divided and sold for pulpwood, sawlogs or veneer logs or combinations of these.

Winch - a device using a wire rope around a mechanically driven drum and attached to a skidder or farm tractor to enable trees or bundles of trees to be dragged from the felling site to roadside.

Wire Loader - a small, crane-like device fitted with wire rope and attached to a farm tractor. It is used to permit loading of trees or bundles of trees onto trucks or trailers by one man working alone.

APPENDIX II

CONVERSION FACTORS

Fuel density

1 kg/m^3 (kilogram per cubic meter)	= 0.062 lb/ft^3 (pounds per cubic foot)
	= 0.001 g/cm^3 (grams per cubic centimeter)

Fuel weight

1 kg	= 2.205 lbs.

Energy equivalents

1 kWh (kilowatt-hour)	= 3,413 Btu (British thermal units) = 3.6 MJ (megajoules)

Power equivalents

1 kW (kilowatt)	= 3,413 Btu/hr
	= 1.341 horsepower (electric or mechanical)
	= 0.102 boiler horsepower

Wood Chip - Oil Equivalents

No. 2 Fuel Oil

100 Imperial gallons - contain about 16,700,000 Btu of energy
- requires about 16 cubic feet of space

Mass density is about 8.3 lb/cubic foot
Higher heating value is about 19,500 Btu/lb or 1,040,000 Btu/cu ft.

Wood chips, 20% MC (dry basis), hardwood

1 tonne - contains about 16,000,000 Btu of energy
- requires about 150 cubic feet of space

Mass density is about 14.2 lb/cubic foot (if not compressed)
Higher heating value (at 0% MC) is about 8,600 Btu/lb or 100,000 Btu/cu ft.

$$\text{Higher heating value at any MC} = \frac{8600 \text{ Btu/lb}}{1 + 0.01 \text{ MC}}$$

APPENDIX III

COMBUSTION EFFICIENCY CURVES

The following curves are taken from the publication by R.C. Hill with the author's permission. (See Appendix V for the reference). The authors have added scales to incorporate use of SI units and have retitled Figures III.2 to III.4 in terms of moisture content on a dry basis.

To use the curves, measure percent CO_2 and the temperature of the stack gas (see text section 5.6 (c) and (d)). Find the moisture content of the fuel (see section 7.1). If time does not permit determination of MC, use Figure III.3 since seasoned chips will have MC of about 25 percent.

1. Knowing CO_2, use Figure III.1 to find the excess air percent.
2. Select from Figure III.2 to Figure III.4 depending on MC. Knowing excess air percent and stack gas temperature, use the appropriate figure to find the combustion efficiency.

See the example given in section 5.6 (f).

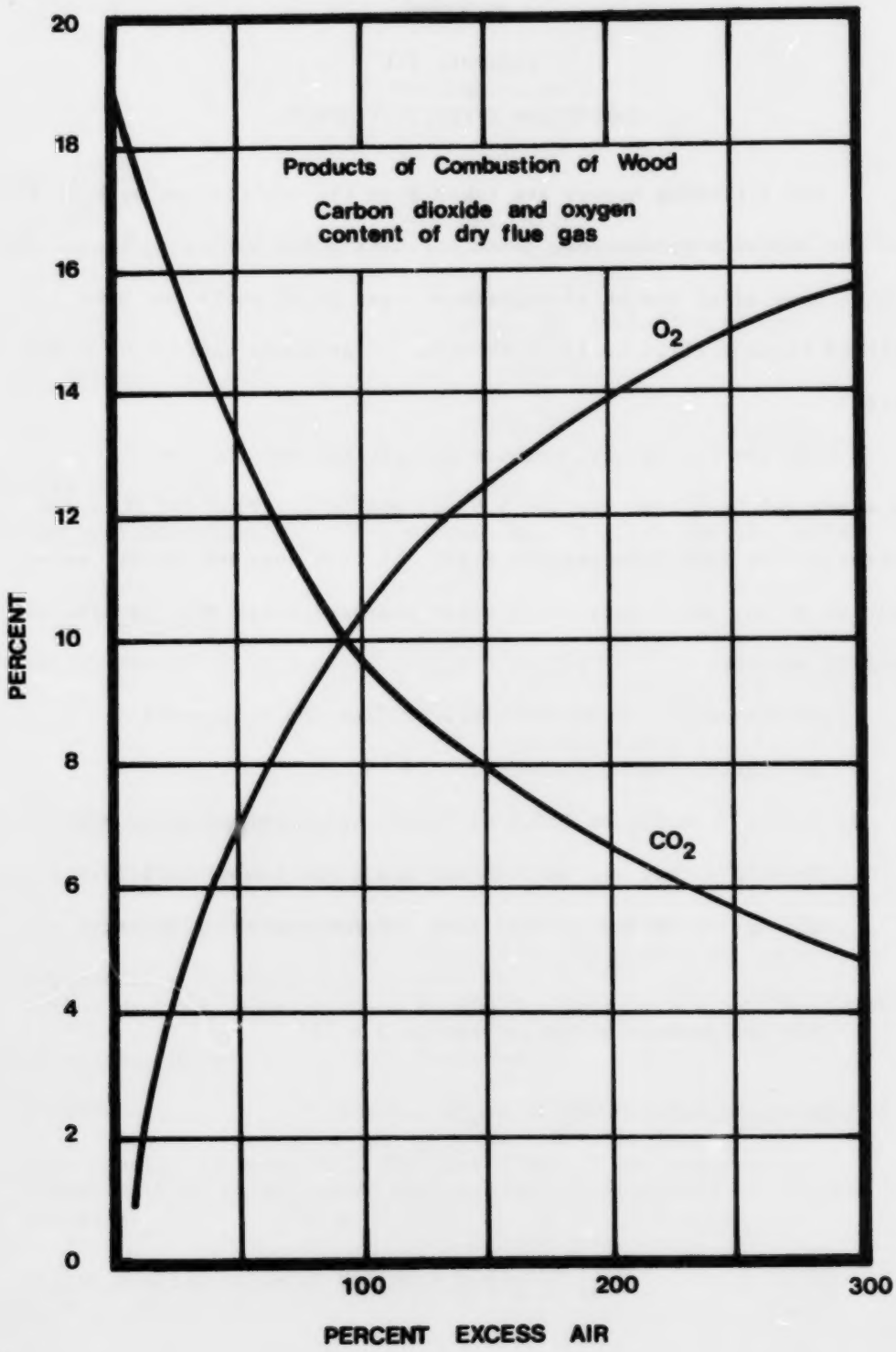


Figure III.1
Excess Air Curves

The Efficiency and Stack Loss from the Complete Combustion of wood as a Function of Stack Temperature and Percent Excess Air.

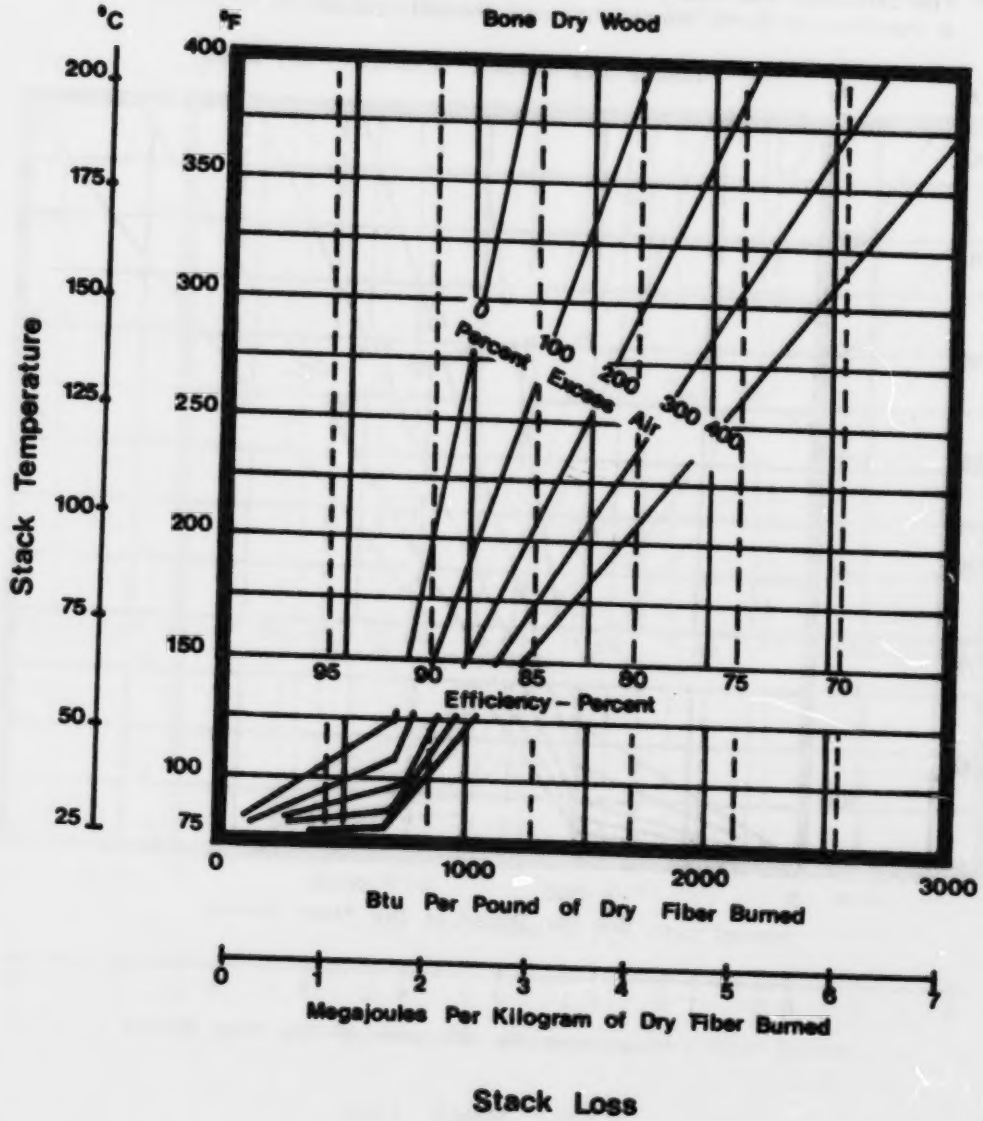


Figure III.2

The Efficiency and Stack Loss from the Complete Combustion of wood as a Function of Stack Temperature and Percent Excess Air.

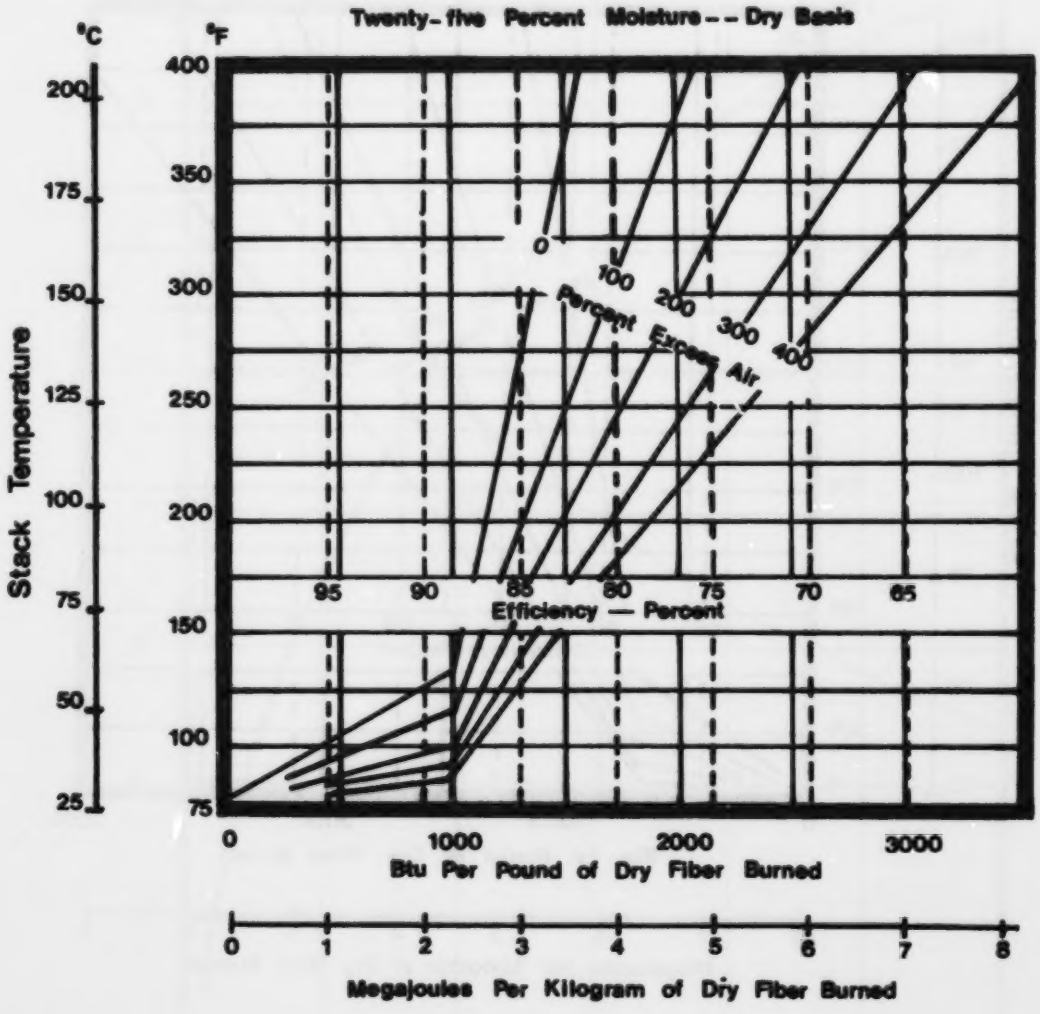


Figure III.3

The Efficiency and Stack Loss from the Complete Combustion of wood as a Function of Stack Temperature and Percent Excess Air.

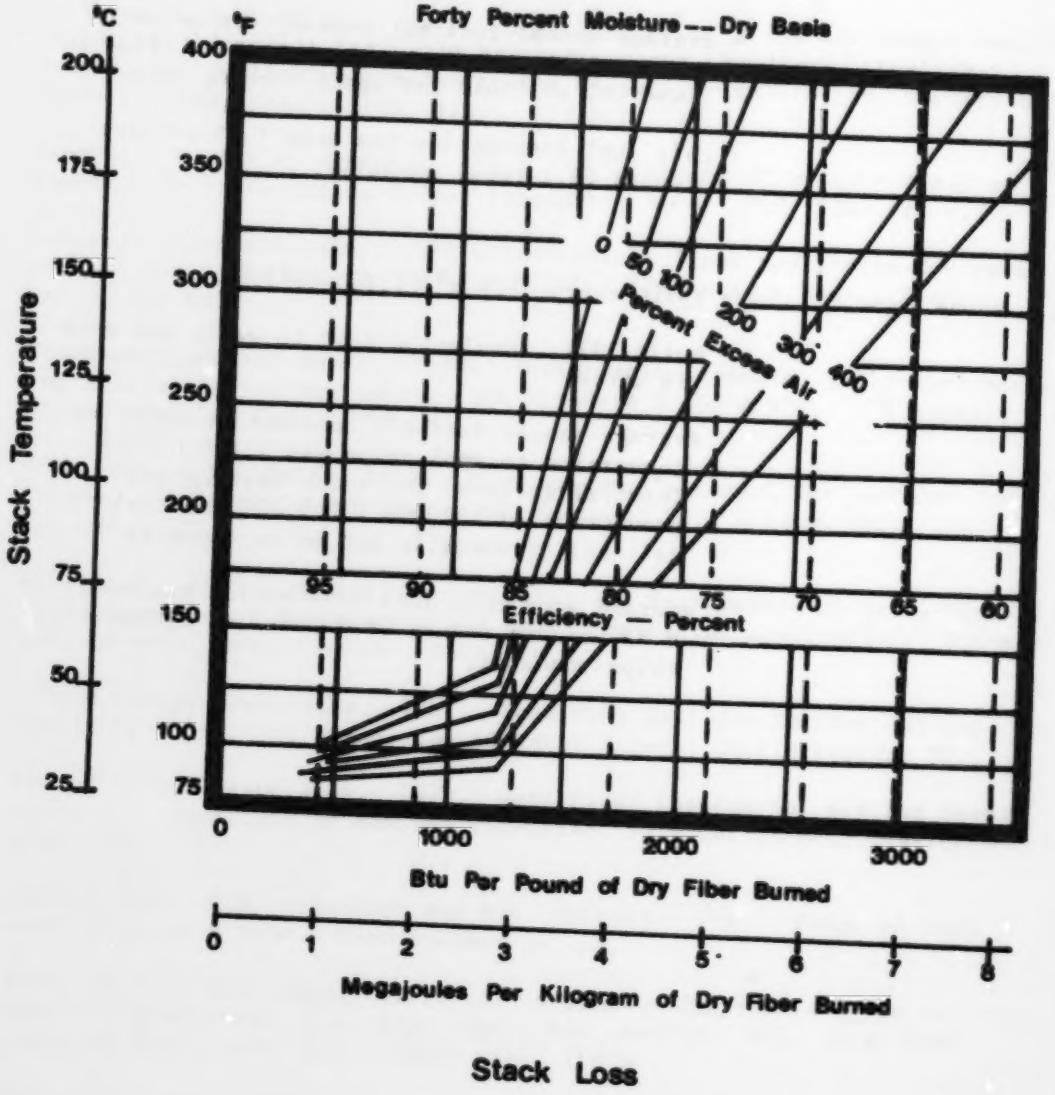


Figure III.4

APPENDIX IV

SPECIFICS OF FREDERICTON HOUSES HEATED WITH WOOD CHIP STOKERS (Climate has 4700 Celsius Heating Degree Days)

1. House Type:
   - 1-1/2 storey, 131.5 m^2 (1,415 ft^2)
   - built 1840, insulated to mid 1950's levels
   - average annual fuel oil consumption prior to conversion to wood chips was 3,900 l (850 Imperial gallons) for space heating only
   - chip fuel consumption has been 7.35 ovendry tonnes (8.1 tons) annually.

2. House Type:
   - split entry, 107 m^2 (1,150 ft^2)
   - built 1971, insulation R-12 in walls and R-40 in attic
   - average annual fuel oil consumption prior to conversion to wood chips was 4,160 l (915 Imperial gallons) for space heating and production of 132,000 l (29,000 Imperial gallons) of domestic hot water annually
   - average wood chip fuel consumption has been 8.33 ovendry tonnes (9.2 tons) of hardwood chips annually.

APPENDIX V

GUIDE FOR FURTHER READING
(Most of the following publications can be purchased from their publishers).

Assoc. Committee on the Building Code, National Research Council of Canada. 1977. Canadian heating, ventilating and air-conditioning code; subsections 2.3-5 & 9.34.2-10. NRCC No. 15560, NRC, Ottawa, Ont.

Beijbom, L. & M. Nilson. 1979. Chip heating of farms and single family homes. Silviconsult Ltd., 230 Bjerred, Sweden (Swedish). English translation available from Continuing Education in Forestry, Faculty of Forestry, UNB, Fredericton, N.B. E3B 6C2. 50 p.

Bramhall, G. & R.W. Wellwood. 1976. Kiln drying of western Canadian lumber. Forintek Canada Corp., Vancouver, B.C. V6T 1X2. 112 p.

Canadian Standards Assoc. 1981. Solid-fuel fired appliances for residential use. CSA Standard B366.1-M1981. 178 Rexdale Boul., Rexdale, Ont. M9W 1R3.

Canadian Standards Assoc. 1980. Installation code for solid-fuel burning appliances and equipment. CSA Standard B 365-M1980. 178 Rexdale Boul., Rexdale, Ont. M9W 1R3.

Cech, M.Y. & F. Pfaff. 1977. Kiln operator's manual for eastern Canada. Forintek Canada Corp., 800 Montreal Rd., Ottawa, Ont. K1G 3Z5. 189 p.

Hill, R.C. 1979. Design, Construction and Performance of Stick Wood Fired Furnace for Residential and Small Commercial Application. University of Main, Orono, Maine 04469, U.S.A.

Island Energy Associates. 1981. Wood Chip Fuel for Residential Use. Institute of Man and Resources, 50 Water Street, Charlottetown, PEI.

Island Energy Associates. 1979. Wood Fired Residential Heating Demonstration. Institute of Man and Resources, 50 Water Street, Charlottetown, PEI.

Miller, D.A., M.H. Schneider and N.L. Whitney. 1982. Fungi on fuel wood chips in a home. Wood & Fiber 14 (1).

Rietz, R.C. & R.H. Page. 1971. Air drying of lumber: a guide to industry practices. U.S. Dept. Agr., Agr. Handbk. 402. U.S. Govt. Printing Off., Wash. D.C. 20402 USA. 110 p.

Schneider, M.H. 1980. A Wood-Chip Fired Hot-Air Home Heating System. Proc. of the Joint Solar Conference. Vancouver, B.C. (SESCI).

Shelton, J.W. 1979. Wood heat safety. Garden Way Publishing, Charlotte, Vt. 05445. USA. 165 p.

Short, C.A. 1981. Home Heating with Wood Chips. Proc. Intnl. Conf. on Residential Solid Fuels, Oregon Graduate Confer. Beaverton, Oregon, U.S.A.

U.S. Dept. of Agriculture. 1979. A guide to the recent literature on aspergillosis as caused by Aspergillus fumigatus. Science & Education Admin., Agric. Reviews & Manuals, N.E. Series No. 5. Available: Biological Waste Mgt. & Organic Resources Lab., Beltsville Agric. Res. Center W., Beltsville, Md. 20705, USA.

APPENDIX VI

PERSONAL INDEX

Subject	Page #